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Sedimentation rates and metal retention in an urban Louisiana swamp

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**SEDIMENTATION RATES AND METAL RETENTION
IN AN URBAN LOUISIANA SWAMP**

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

Department of Oceanography and Coastal Sciences

by

Renee Lynn Sanders

B.S., The University of Tennessee, Knoxville, 1998

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ABSTRACT

Naturally vegetated areas converted to urban uses increases impervious surfaces in a watershed with corresponding increases in nutrient, sediment, and metal loadings to downstream ecosystems. Wetlands mitigate detrimental impacts by transforming or retaining pollutants. Current and historic sedimentation and metal retention rates were measured in an urban, depressional wetland in Baton Rouge, Louisiana to evaluate landscape position and watershed development on these processes. Sedimentation disks, feldspar marker horizons, and Cs¹³⁷ analyses were used in three distinct landscape positions. Inflow channels had the highest elevation and water velocity while the interior was located in the lowest elevations with the longest hydroperiod. An intermediate elevation between the channel and interior was designated as the transitional landscape position. Sedimentation disks yielded significant differences ($p = 0.009$) in sedimentation rates between the channel ($23.8 \pm 5.43 \text{ g/m}^2/\text{d}$) and transitional ($37.1 \pm 5.09 \text{ g/m}^2/\text{d}$) landscapes. The interior ($27.9 \pm 4.65 \text{ g/m}^2/\text{d}$) position was not significantly different. Feldspar data yielded comparable values for the transitional ($29.6 \pm 2.57 \text{ g/m}^2/\text{d}$) and interior ($27.2 \pm 3.64 \text{ g/m}^2/\text{d}$) locations, which were not significantly different ($p = 0.35$). A historic sedimentation rate of $0.49 \text{ cm/yr} \pm 0.11 \text{ cm/yr}$, calculated from Cs¹³⁷ analysis, was significantly lower than the current rate of 2.95 ± 1.10 ($p = 0.010$). Lead, Cd, Cu, Zn, Ni, and P sediment concentrations were significantly greater ($p < 0.05$) in the interior than the transition based on sedimentation disks. Sediment metal concentrations were normalized with Al to compensate for increases in metal concentration with increasing clay content. Significantly higher Al content in the

interior resulted in either no differences between the interior and transitional locations or significantly lower concentrations in the interior after Al-normalization. Historic metal retention rates (background concentrations) were calculated for depths below the 1963 Cs¹³⁷ peak. Metal/Al ratios from soil cores yielded significantly higher Cd, Cr, Cu, Zn, Ni, and P concentrations in sediments deposited since 1963. These higher concentrations correspond with a seven percent increase in developed area surrounding Bluebonnet Swamp from 1963 to 2000. This urban wetland functions as an important sediment and pollutant sink, and protects downstream aquatic ecosystems.

CHAPTER 1: INTRODUCTION

Background

Wetlands have been cleared and converted to agriculture since the arrival of the Europeans to North America. They were previously thought of as worthless and unimportant. Now regulated under the Clean Water Act of 1972 and administered by the U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency, the Act regulates all draining and filling activities associated with “waters of the U.S.,” of which wetlands are a subset (Coreil, 1994). The Act also regulates the restoration and maintenance of the chemical, physical, and biological integrity of the nation’s waters.

There are three main categories of wetland functions: hydrologic, biogeochemical, and habitat and food web support. Hydrologic functioning of wetlands includes short-term and long-term water storage, as well as the maintenance of a high water table. This function acts to reduce downstream flooding, maintain base flow, and support a hydrophytic vegetative community. Biogeochemical functioning includes the retention of substances (nutrients or sediment), elemental cycling of nutrients, and the accumulation of mineral and organic matter. Downstream water quality benefits from the reduction in sediment and chemical loads from upstream wetlands. Wetlands also provide a habitat and food web for flora and fauna to flourish (Preston and Bedford, 1988; Coreil, 1994; Brinson, 1995).

The rate of wetland loss, in general, reached its peak between the 1950s and 1970s (King and Allen, 1996). Losses occurred through draining and clearing,

stream channelization, freshwater flow restrictions such as levees and impoundments, subsidence, wave erosion, saltwater intrusion, relative sea level rise, tropical storms and hurricanes, and agricultural conversions (Wilber, et al., 1996). Urbanization, the primary factor impacting the wetland in this study, includes road and housing development causing sediment disturbances, the input of herbicides, pesticides, and fertilizers, and urban stormwater runoff.

Land Use Conversions

Land use conversion from forest into an urban environment increases the amount of impervious surfaces. As urban area increases, average annual sediment load decreases since impervious surfaces are no longer a source of sediment (Gellis, et al., 1999). However, during the conversion process, sediment disturbance results in an increase in short-term episodic sediment influxes and a decrease in long-term sediment accretion rates. As conversion of forested land to urban land increases, so do the types and sources of pollutants. Urbanization generates non-point-source pollution from fertilizers, pesticides, and urban stormwater runoff, septic tanks, construction sites, and roadway development. Pollutants of this kind have negative effects on water quality and retention functions for those wetlands within an urban environment.

Characteristics of Bottomland Hardwood Forests

Bottomland hardwood (BLH) forested wetlands inhabit the floodplains of southern and southeastern rivers of the United States including Louisiana. Occupying the lower portion of the landscape, bottomland hardwood forests typically function as sinks for the deposition of materials from surrounding upland

environments. Although the study site is no longer flooded by the Mississippi River, parent material is primarily associated with previous overbank flooding resulting in the accumulation of alluvium sediment. This alluvium is comprised of montmorillonite, mica-illite, and vermiculite, as well as, feldspar, quartz, and hydroxides of iron.

Vegetation typically found in depressional areas and bottomland hardwood forests include: water tupelo (*Nyssa aquatica*), cypress (*Taxodium distichum*), black willow (*Salix nigra*), and Drummond red maple (*Acer rubrum* var. *drummondii*). Vegetative speciation development in bottomland hardwood forests is influenced by frequency, duration, and timing of flooding, soil type, and depth to water table (Bedinger, 1981). Timing and duration water inundation affect the anaerobic and aerobic soil environments, thereby causing different zones of plant speciation. Only those species adapted to wet soils can thrive in poorly drained, anaerobic conditions that exist in the low depressional areas. Since bottomland hardwood forests need to be regularly flooded in order to sustain native vegetation, any activity that changes the hydrologic cycle will have a negative effect on vegetative composition. Such activities, like forest clearing and road development occurring within the watershed, can lead to changes in water quality and sediment retention functioning of that wetland.

Water Quality and Sediment Retention

Temporary or permanent removal pathways, such as plant uptake, adsorption and precipitation processes, and sediment retention, affect nutrient and contaminant detention and transformations. Sediment retention is influenced by landscape

position, ground surface roughness, landscape gradient, vegetative cover, and water velocity. For example, a decrease in vegetative cover and an increase in water velocity result in decreased sediment retention. One water quality function associated with a depressional forest is sediment, nutrient, and contaminant retention (Scott, et al., 1990).

Retention of sediment and nutrients can be both beneficial and detrimental to a wetland ecosystem. Increased turbidity caused by increased suspended solids negatively affects phytoplankton production and biological oxygen demand issues (Kleiss, 1996; Boto and Patrick, 1978). However, sedimentation of clay particles high in adsorbed metals decreases metal concentrations downstream and metal cycling throughout the food chain. Depending on pH and redox conditions affecting metal speciation, possible permanent burial of pollutants attached to sediment particles could occur (Boto and Patrick, 1978).

Measuring Sedimentation Rates

Various techniques have been used to measure current and historic sedimentation rates. Current rates of sediment transport have been determined using feldspar marker horizons and sedimentation disks (Kleiss, 1996; Heimann and Roell, 2000); whereas, historic sedimentation patterns have been measured using the dendrogeomorphic approach and cesium analysis (DeLaune, et al., 1978; Hupp and Bazemore, 1993; Phipps, et al., 1995; Lowrance, et al., 1988; Cahoon and Turner, 1989). Hupp and Bazemore (1993) identified two bottomland hardwood forested wetland sites in west Tennessee to measure the effects of bridge and causeway construction on sedimentation patterns using the dendrogeomorphic and the feldspar

marker horizon approach. Their study revealed sedimentation rates in close agreement and comparable with other published rates (0.24 to 0.28 cm/yr). Heimann and Roell (2000) studied sedimentation rates in a temporary sediment storage area along a stream in Missouri and determined that the sediment deposition rate was 1 cm/yr. The sedimentation rates were identified using the dendrogeomorphic approach, feldspar marker horizons, and sedimentation disks.

Like Kleiss (1996), the use of feldspar clay marker horizons revealed higher sedimentation rates than those found using the dendrogeomorphic approach. Having studied sedimentation rates in a freshwater wetland system in Arkansas over a three-year period, Kleiss (1996) determined a 1 cm/yr sedimentation rate where *Nyssa aquatica* and *Taxodium distichum* dominated.

Cesium (Cs^{137}) analysis has been used in several different environments to estimate sediment accretion, from a valley landscape position to a rapidly accreting salt marsh (Lowrance, et al., 1988; DeLaune, et al., 1978). Because cesium is a fallout product from nuclear testing, has a half-life of 30 years, and is not a naturally occurring element, it is a reliable tracer for historic sedimentation and erosion patterns (Wallbrink and Murray, 1993; Ritchie and McHenry, 1990; Lowrance, et al., 1988). Peak Cs^{137} activity occurred in 1963 when the Test Ban Treaty was signed ending atmospheric nuclear testing (Ritchie and McHenry, 1990). Cesium analysis would not be an effective method for sediment deposition analysis in aread where plowing has resulted in the mixing of the Ap horizon or in areas where dredging or physical soil disturbances have occurred (Ritchie, et al., 1974).

Factors affecting accurate results Cs^{137} activity include the physical reworking of sediments through bioturbation, diffusion, and interstitial movement reducing cesium concentration, and biological uptake by plants. Minimum Cs^{137} migration occurs through biological (plant uptake) and chemical processes, as movement occurs primarily through erosion and deposition (Cooper, et al., 1987; Ritchie and McHenry, 1990; McIntyre and Naney, 1991). If the rate of sedimentation is low, the effects of reworking of sediments and redistribution of cesium are greater (Cahoon and Turner, 1989). Very little movement of cesium occurs through diffusion and interstitial movement in clay soils, as the cesium binds readily with clay particles (Ritchie, et al., 1975; Cahoon and Turner, 1989). Cesium measurements are also affected by uneven sedimentation patterns, like those often found in urban environments where the sedimentation rate varies with surrounding soil disturbances.

Metal Retention

Temporary or permanent removal pathways, such as plant uptake, adsorption and precipitation processes, affect nutrient and metal retention and transformations. Studies have shown that metals are more closely associated with the silt and clay soil fractions. Metal retention is affected by retention time of water within a topographic landscape position, as well as water velocity, texture of the incoming sediment, pH, and redox conditions (Gambrell, et al., 1983; Puckett, et al., 1993). Depressional wetlands can function as temporary or permanent removal of metals through soil burial (Puckett, et al., 1993). Urban depressional wetlands often have more than one source and have changing sources of metal inputs. An example of a changing metal

source in urban wetlands is lead. Having become a gasoline additive in 1923 to boost the octane quality of fuel, lead particles (0.01 μm) are emitted in the exhaust gases during combustion and can be transported over long distances through the wind. Lead content in the air and soil is dependent on traffic density, road width, location of the source, and air movement (Hutchinson and Meema, 1987; Elsom, 1996).

Aluminum Normalization

Aluminum normalization has been successfully used to evaluate soil contamination by compensating for the effects of increasing metal concentration with increases in clay content (Pardue, et al., 1992; Summers, et al., 1996). Along with iron, total organic carbon (TOC), and particle size, are other normalizers for trace element concentrations. Extractable Al has a naturally high concentration in the environment because it is a major component of soil structure, especially clays, and it does not have a significant anthropogenic source (Daskalakis and O'Connor, 1995; Summers, et al., 1996). However, TOC can be easily influenced by human activities; therefore, TOC can be a poor normalizer in urban environments.

Metal ($\mu\text{g/g}$)/%Al ratios are calculated by plotting metal concentration versus %Al. A linear regression line and 95% confidence level intervals for the regression line were then created. Data points (metal concentrations) plotted above the upper confidence level interval are suspected to be areas of contamination (Pardue, et al., 1992; Summers, et al., 1996; Daskalakis and O'Connor, 1995). Since background concentrations of metals vary with soils, metal ($\mu\text{g/g}$)/%Al ratios will vary. In addition, metal concentration in soil can be influenced by anthropogenic activities.

Pardue, et al., (1992) developed background ratios for coastal Louisiana soils for Pb, Cd, and Cr. These ratios are applicable background ratios to this study site, as the site was previously flooded with the same sediment that has accumulated within coastal regions of Louisiana. Using background metal ($\mu\text{g/g}$)/%Al ratios, anthropogenic metal inputs can be identified.

Research Objectives

Objectives of this study include quantifying sedimentation and metal retention rates within a depression, urban wetland and determining if metal retention within the swamp is being affected by anthropogenic activities within the watershed.

CHAPTER 2: SEDIMENT RETENTION IN AN URBAN SWAMP

Introduction

Wetlands benefit downstream ecosystems by functioning as a water storage basin and sink for sediment and nutrient retention. Sediment retention is influenced by landscape position, as well as ground surface roughness, landscape gradient, vegetative cover, water velocity, and the size and shape of the storage basin area. Decreased sediment retention can occur from a decrease in herbaceous vegetative cover and increase in water velocity and soil disturbances upstream (Scott, et al., 1990). Prior to retention, sediment erosion is dependent on soil disturbances. Anthropogenic activities causing soil disturbances include road, residential housing, or commercial development. Once exposed, disturbed soil has been covered by impervious surfaces, like roads, the sediment source decreases. The retention function of an urban swamp, like Bluebonnet Swamp, benefits downstream water bodies by decreasing total suspended solids, metal concentrations, and excess nutrients prior to (Boto and Patrick, 1978; Johnston, et al., 1984; Preston and Bedford, 1988; Coreil, 1994; Brinson, 1995; Craft and Casey, 2000).

Sediment retention reduces biological oxygen demand, total phosphorus, conductivity, ammonia, nitrate, coliform bacteria, and turbidity in downstream water bodies (Boto and Patrick, 1978; Kleiss, 1996). A high concentration of total suspended solids in the water column affects turbidity, light attenuation, phytoplankton production, and biological oxygen demand (Boto and Patrick, 1978). Hence sediment retention, in a wetland basin like Bluebonnet Swamp, can improve

downstream water quality by removing suspended solids and contaminants from the inflowing water.

In addition to sediment retention, wetlands detain and transform nutrient and contaminant influxes (Scott, et al., 1990). Metal concentrations downstream and metal cycling throughout the food chain decrease by retention processes like cation exchange capacity and sediment burial. Depending on pH and redox conditions affecting solubility, possible permanent burial of pollutants attached to sediment particles could occur (Boto and Patrick, 1978). Removal of a pollutant is also dependent on the type of sediment and the sediment volume entering the wetland. Clay particles have a greater surface area and a greater cation exchange capacity; thereby, retaining more contaminants. Soils high in clay can be found in areas of high organic matter and in oxidized environments where more iron oxides are present.

Sediment accumulation rates vary based on surrounding land use characteristics, soil properties, vegetation cover, water flow velocities, suspended sediment load, and topography characteristics (Hupp, et al., 1993; Phipps, et al., 1995). Sedimentation rates are also dependent on debris within the stream channels blocking the flow while redistributing water and sediment influx to a new location. In this experiment, retention variabilities could have resulted from the aforementioned issues, as well, as from sediment redistribution between sampling events. Due to these known issues, this experiment used replicated plots to minimize possible sediment rate variations.

Research Objectives

The objectives of this study were to quantify sedimentation rates within an urban wetland and to determine if sedimentation rates are being affected by urbanization within the watershed.

Materials And Methods

Study Area

Bluebonnet Swamp was chosen because of its position in a rapidly developing urban watershed in Baton Rouge, Louisiana (Figure 2.1). While the watershed includes approximately 50,586 ha (125,000 ac) of land, Bluebonnet Swamp covers only 42 ha (105 ac). The Y-shaped swamp is approximately 1.609 km long and 183 m (600 ft) wide (Dr. Mitchell, personal communication). There is a 6-meter drop in elevation from the escarpment to the cypress-water tupelo (*Taxodium distichum*-*Nyssa aquatica*) swamp. Bluebonnet Swamp is now surrounded by residential and commercial development. At the southern end of the swamp, a road restricts water outflow.

Sediment and Metal Sampling

Six distinct inflow points with erosional channels were identified within Bluebonnet Swamp (Figure 2.1). These erosional channels carry upland runoff into low-slope transitional areas (dominated by boxelder (*Acer negundo*), sweetgum (*Liquidambar styraciflua*), and American elm (*Ulmus americanus*)), and interior depressional landscape areas (dominated by cypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*), sugarberry (*Celtis laevigata*), and smartweed (*Polygonum* spp.)). Stratified into channel, transitional, and interior landscape positions, the sites

for each stratum were randomly selected. Replicated sedimentation disks were used to measure current sedimentation rates within each stratum.

The channel landscape positions were located in erosional drainage channels entering Bluebonnet Swamp. The channels contained sandy soils and had little to no vegetation within them. Three replicated disks were established within each channel. Transitional landscapes, having contained soil with a silt loam texture, had a slope less than that of the erosional channels and greater than that of the interior areas. Little topographical relief, and Fausse (silty clay loam) soils characterized the interior/depressional landscapes (Dr. Faulkner, 1998). Three replicated plots of six disks were installed within the transitional and interior landscape areas.

The soils found along the terraces of three sides of the swamp are Terrace Escarpment soils (USDA Soil Survey Staff, 1968). These terraces are highly erodible and are often dissected by ravines and drainageways. The southwest side of the swamp has Waverly-Falaya silt loams, overflow which are poorly drained and frequently flooded. The outer perimeter of the swamp is comprised of primarily two types of soils, which are Calhoun silt loam and Oliver silt loam, 0-1 percent slopes. These two soils have slow runoff and slow permeability characteristics.

Louisiana receives more than 10.2 cm of rain per month with an annual average of 139 cm (USDA Soil Survey Staff, 1968). Daily rainfall values were collected from a Louisiana Office of State Climatology location a few miles south of Bluebonnet Swamp. Because the wetland is located in a topographic depression, the water becomes centralized in the interior portion of the swamp, which then drains into Bayou Fountain located south of the swamp.

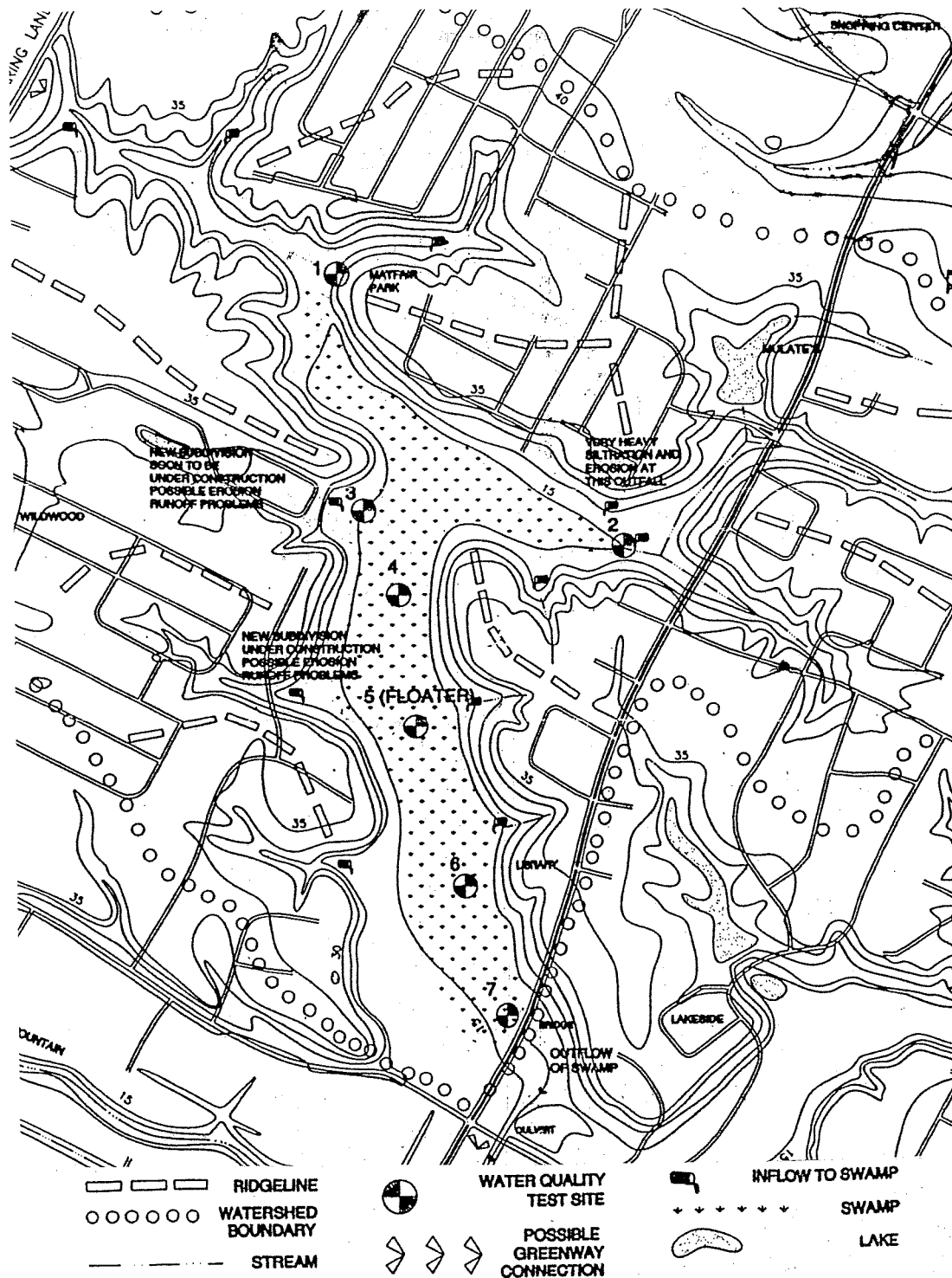


Figure 2.1. Point source inflow locations into Bluebonnet Swamp, Baton Rouge, Louisiana, USA. Map source is BREC Planning and Engineering Department.

Each disk consisted of a 12.7 cm diameter plexiglass disk with a hole drilled in the center (Kleiss, 1996; Heimann and Roell, 2000). Non-galvanized, 15.3 cm long nails were used to anchor the disk. Preparation of the sites for sedimentation disks began by scraping the soil surface to a depth equal to the thickness of the plexiglass disk (0.318 cm). Each disk was placed, on average, 20 cm apart. Three disks were placed in one row and three in another row just downstream. Depending on space within each designated plot, the two rows were either placed offset from one another or directly behind one another. The distance between the two rows (measuring from the perimeter of the two disks) was on average 15 cm.

Feldspar Marker Horizon Establishment

Feldspar marker horizons were also used to characterize current sedimentation patterns. The advantage of feldspar is that it is an inexpensive, simple, fast way to measure short-term accretion rates (≤ 1 yr) (Cahoon and Turner, 1989). Six separate 30.5 cm by 30.5 cm square feldspar marker positions were located at each site. Each feldspar position was dug with a shovel to a depth of 5 cm. The feldspar clay was used to fill the hole and was smoothed flush with the soil surface. All feldspar pots were installed on August 24, 2000 and later sampled on May 21, 2001.

Sample Collection

To identify short-term sedimentation rates, every thirty days or after a rain event, each sediment disk was gently lifted and trimmed with scissors to remove any leaf matter extending over the edge of the disk. A putty knife was used to remove recently accumulated sediment from the disk into a polyethylene bag. Any

remaining sediment was rinsed with deionized water into a polyethylene bag and the disk was then replaced in its original position.

Soil collection also occurred through the use of feldspar marker horizons. Retrieval of the sediment samples from the feldspar marker positions began by removing twigs and leaves from the soil surface. Six separate 30.5 cm by 30.5 cm square feldspar marker positions were located at each site. Each feldspar position was dug with a shovel to a depth of 5cm. The feldspar clay was used to fill the hole and was smoothed flush with the soil surface. A hollow, clear plexiglass tube (10.2 wide and 10 cm long) was twisted into the ground. Where the ground was dry and hard, a piece of plywood and rubber mallet was used to gently hammer the tube into the ground until one half-inch remained above the ground surface. Each tube was dug out of the ground with a spade and placed in a polyethylene bag. All feldspar pots were installed on August 24, 2000 and later sampled on May 21, 2001.

The depth of the sediment overlying the feldspar marker horizon was measured at four points around the edge of the core. The soil sample above the feldspar was dried, weight, and bulk density was determined. Using direct measurements from the feldspar marker cores, sediment accumulation per year for a given area could then be determined with the following equation (Lowrance, et al., 1988; Downer, et al., 1995):

$$S.A. = \rho_B * \%MM * V.A. * 10,000 \text{ cm}^2/\text{m}^2 \quad (\text{Equation 1})$$

where

S.A. = Sediment accumulation ($\text{g}/\text{m}^2/\text{yr}$)

ρ_B = Soil bulk density, (g/cm^3)

%MM = Percent soil mineral matter

V.A. = Vertical accretion, (cm/yr)

Percent soil mineral matter was determined from the carbon content of the sediment overlying the feldspar marker using a Perkin and Elmer 2400 CHN elemental analyzer.

Sample Analysis

To determine a mass value of sediment for each site, the soil was removed from the bags and screened through a 2-mm sieve. Each bag was rinsed several times with deionized water until all visible sediment was retrieved. All material, such as leaves and twigs, greater than 2-mm was discarded. The sieved soil was placed into beakers and dried at 110°C for 24 hours, weighed, and ground using a mortar and pestle to a fine powder.

To determine a mass value of sediment over the feldspar marker horizon, soil was removed by gently scraping the soil surface with a putty knife until reaching the surface of the feldspar material. Samples were then placed in beakers, dried in an oven at 100°C for 24 hours, and immediately weighed. The soil matter was then ground using a mortar and pestle to a fine powder and stored in 250-ml plastic bottles until analyzed. For determination of carbon and nitrogen for sediment samples of the sedimentation disk and feldspar marker horizons, ten milligrams was weighed for each composite sample and was tested using a Perkin and Elmer 2400 CHN elemental analyzer.

Cesium analysis was accomplished by retrieving two cores, one from the interior and one from the transitional landscape positions, using thin-walled

aluminum tubes (DeLaune, et al., 1978; Cahoon and Turner, 1989). The tube was twisted into the ground, pulled out, and then capped at both ends. The maximum depth at which the transitional and interior cores were taken was 46 and 24 cm, respectively. Two-centimeter sections were cut for the entire length of the core and dried at 110°C for 24 hours. Each section was ground using a mortar and pestle and was passed through a 2-mm mesh sieve. The sieved sample was analyzed for cesium concentrations using a Lithium-based Germanium gamma spectrometry system. To calculate vertical accretion per year, the depth at which the maximum activity of Cs^{137} occurs is divided into the number of years between the sampling time and 1963. The maximum activity of Cs^{137} has been established to be the year 1963.

Statistical Analysis

The sedimentation data from the sedimentation disks and feldspar marker horizons were tested for normality and homogeneity using the Shapiro-Wilk and Levene's tests, respectively prior to statistical analyses. Having revealed similar p values of 0.0001 during the non-parametric test, Kruskal-Wallis, the analysis of variance (ANOVA) parametric test was used to perform statistical analyses for the sedimentation disk and feldspar marker horizon data. Since the sedimentation disk data were more normal and homogeneous using a natural log transformation, the transformed data was used in the ANOVA test to identify whether statistically significant differences occurred between the landscapes. Tukey's post-hoc test for pair-wise comparisons was used to identify differences in the three landscape positions: channel, transitional, and interior. An alpha level of 0.05 was used as the

level of significance for all analysis performed. All statistical analyses were performed using SAS (SAS, 1985).

Results

Core Data: Cs¹³⁷ Analyses

The first appearance of Cs¹³⁷ occurred in 1954 when hydrogen bomb testing began, with the greatest peak occurring in 1963. Soil cores in this study did not reach a depth at which the Cs¹³⁷ was no longer detected; therefore, the greatest Cs¹³⁷ activity, 1963, was used as the primary sediment marker within the profile to depict average sedimentation rates over approximately the past 37 years. The 1963 Cs¹³⁷ peak occurred at 15 cm deep for Core #1 (1.142 pCi/g) establishing a historic rate of 0.41 cm/yr (Figure 2.2) and 21 cm deep for Core #2 (0.499pCi/g) establishing a rate of 0.57 cm/yr. It is assumed that the accretion rate for the 37 years after 1963 was constant throughout the two cores.

Core Data: Bulk Density, and Carbon and Nitrogen Content

Bulk density for the sediment within both cores increased gradually as the depth increased (Figure 2.4). The average bulk density for the top 24 cm of the cores was $1.18 \text{ g/cm}^3 \pm 0.071$ and $0.624 \text{ g/cm}^3 \pm 0.044$ for the transitional and interior landscapes, respectively. Carbon content was not taken for the core sections; however, based primarily on bulk density, the interior landscape (Core #1) depicted a more organic soil, whereas the transitional areas (Core #2) depicted a more mineral soil. Average percent mineral matter for Core #1 and Core #2 was $92.5 \pm 0.64\%$ and $93.9 \pm 0.61\%$, respectively. Core #2 (transitional landscape position) contained less organic matter, which could have resulted from a greater decomposition rate of OM.

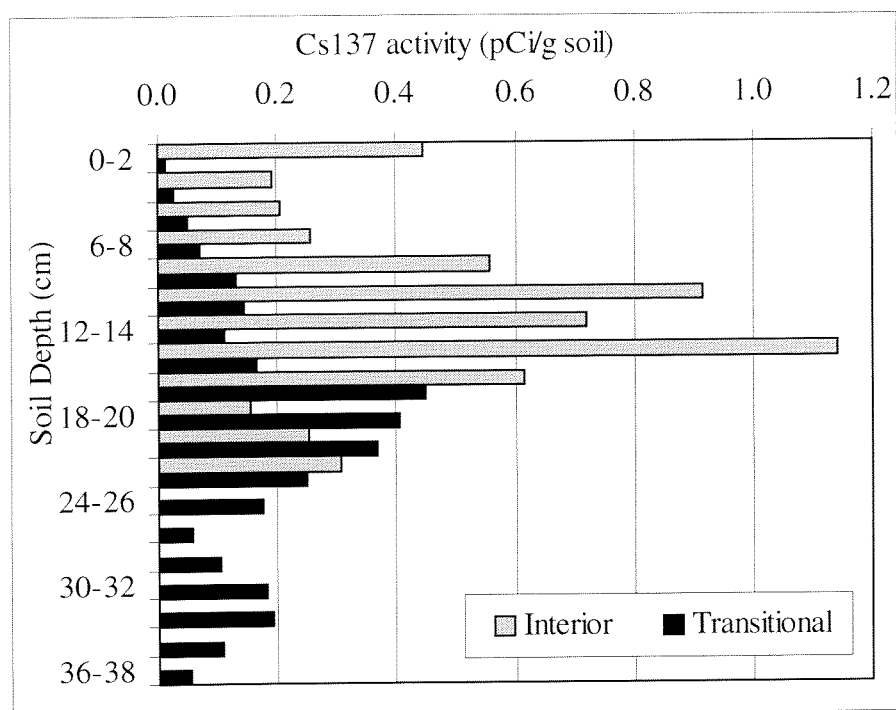


Figure 2.2. Cs^{137} activity of a soil core extracted from an interior landscape position (Core #1) and a transitional landscape position (Core #2) within Bluebonnet Swamp, Louisiana.

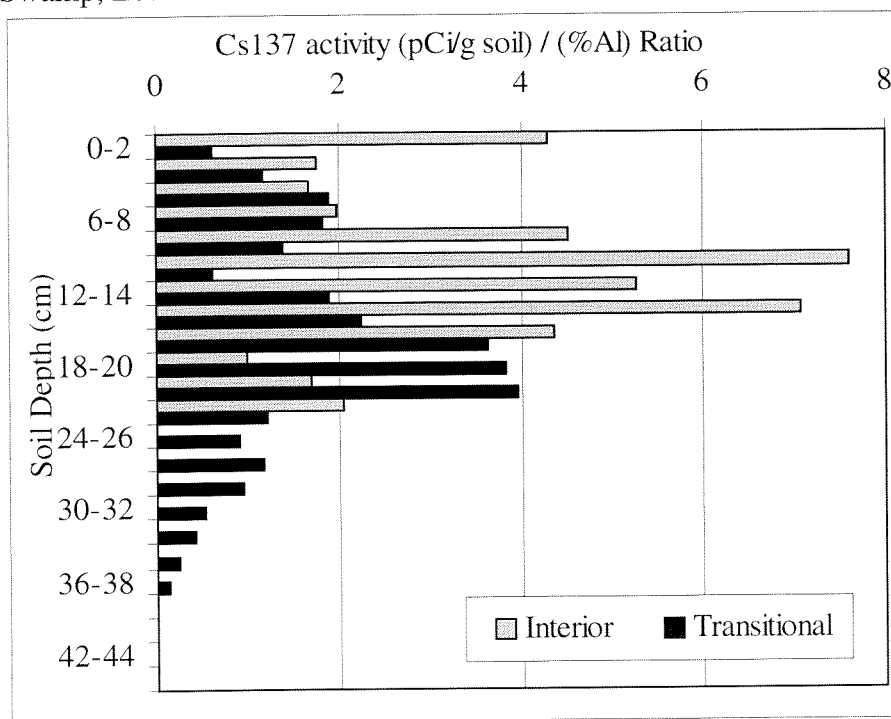


Figure 2.3. $\text{Cs}^{137}/(\% \text{Al})$ ratios for a soil core extracted from an interior landscape position (Core #1) and a transitional landscape position (Core #2) within Bluebonnet Swamp, Louisiana.

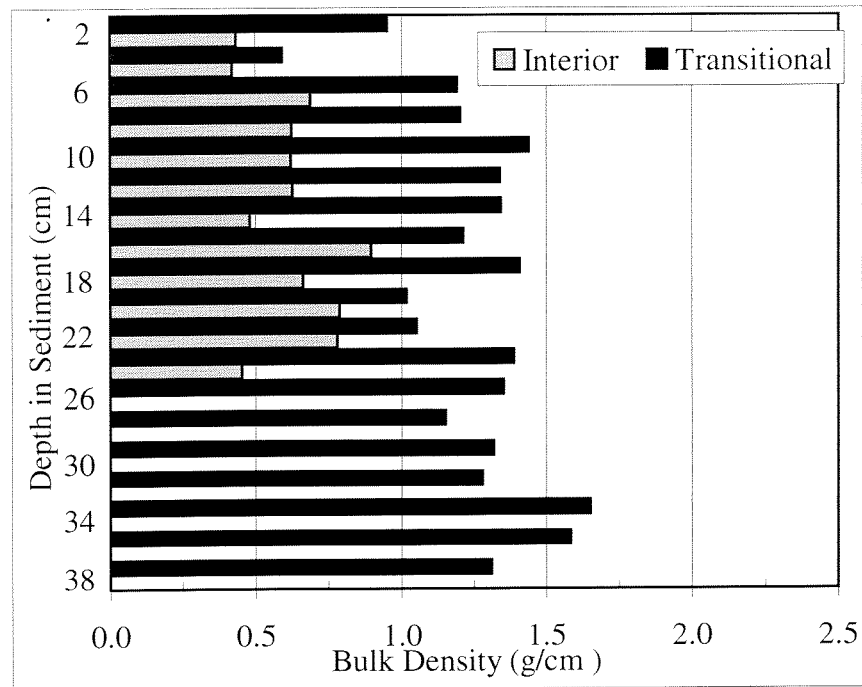


Figure 2.4. Bulk density of a soil core extracted from an interior landscape position (Core #1) and a transitional landscape position (Core #2) within Bluebonnet Swamp, Louisiana.

Feldspar Marker Horizons: Short-Term Sedimentation Results

Feldspar marker horizons were used to determine sedimentation rates occurring over a six-month time interval within the transitional and interior landscape positions. Sediment accumulation overlying the feldspar marker horizon within the transitional and interior landscape positions were $27.20 \pm 3.64 \text{ g/m}^2/\text{d}$ and $29.61 \pm 2.57 \text{ g/m}^2/\text{d}$ (Figure 2.5). The natural log transformed sediment disk data and the raw data for dry weight were tested for homogeneity and normality prior to using a statistical test. Since the homogeneity improved with a natural log transformation, the Tukey's poc hoc test was used. A p value of 0.6303 was calculated revealing there is no significant difference between the interior and transitional landscape positions.

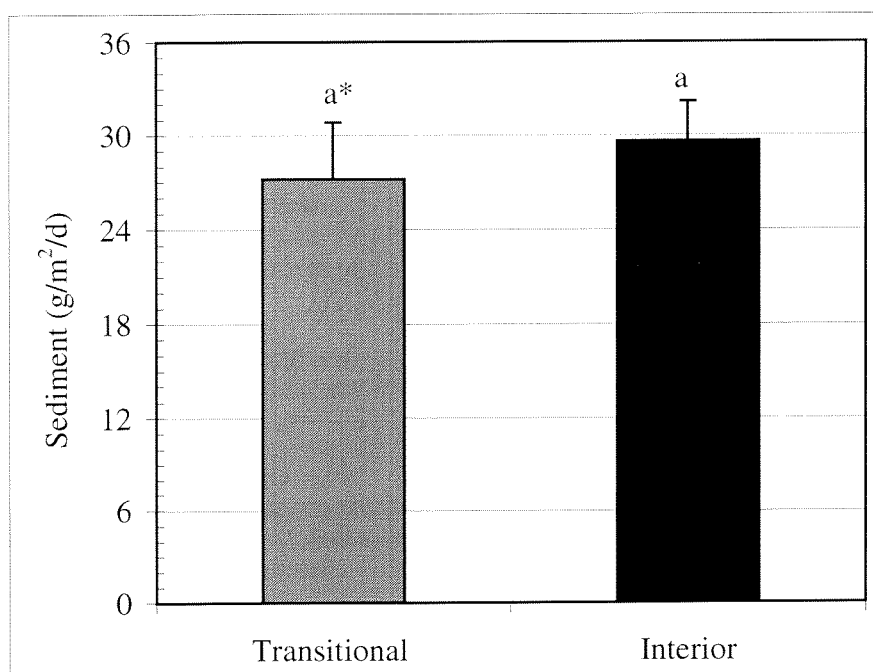


Figure 2.5. Sediment accumulation overlying feldspar plots for the transitional and interior landscape positions. Error bars indicate \pm SE (n=52).

*Treatments with different letters are significantly different at $\alpha = 0.05$.

Average total depth accumulation in the vertical direction overlying the feldspar marker horizon was 0.0061 ± 0.063 cm/day in the transitional landscape position compared to 0.0084 ± 0.036 cm/day of the interior position (Figure 2.6). Average depth accumulation for the year would be 2.23 and 3.07 cm/yr, respectively. Bulk density for the transitional landscape position was 0.5709 ± 0.150 g/cm³ and 0.3359 ± 0.030 g/cm³ for the interior landscape position.

Sedimentation Rate Equation

The sedimentation rate equation (Equation 1) (Lowrance, et al., 1988; Downer, et al., 1995) incorporates physical attributes of sediment vertically accreting above the feldspar marker horizon to estimate sedimentation rates. The sedimentation rate equation converts a direct measurement of height of sediment

accumulation to $\text{g/m}^2/\text{d}$, a value of which is comparable to the other methods in this study. The physical attributes, determined from laboratory analysis, include bulk density and percent mineral matter. By utilizing bulk density, percent mineral matter, and vertical accretion from the feldspar marker horizons, the sedimentation rates for the transitional and interior landscapes were $25.7 \pm 3.57 \text{ g/m}^2/\text{d}$ and $27.7 \pm 2.57 \text{ g/m}^2/\text{d}$, respectively. Because feldspar plots were not established in the channel landscape position, sedimentation rates using Equation 1 could not be calculated.

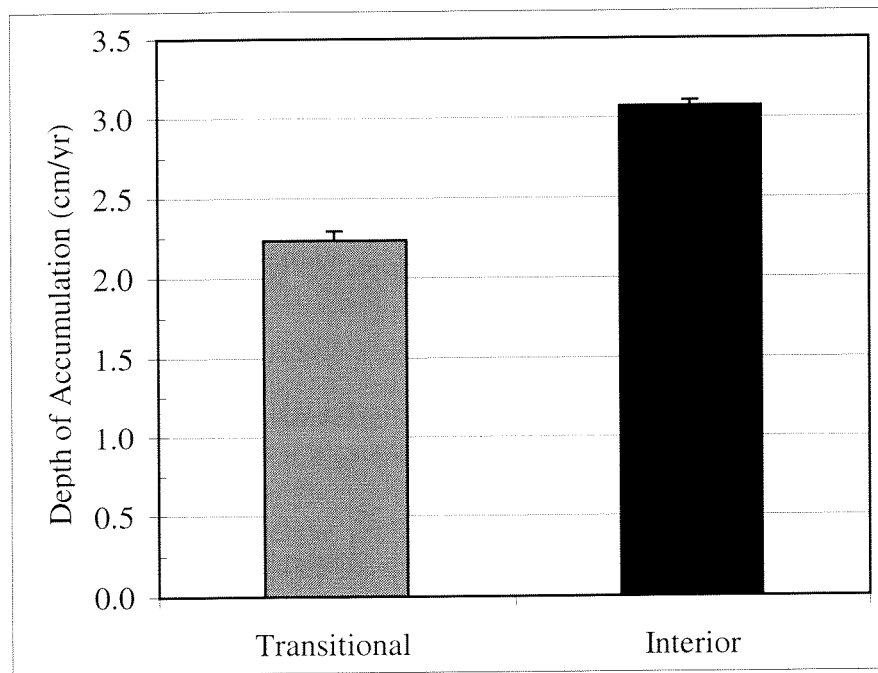


Figure 2.6. Average vertical accretion overlying feldspar marker horizons in cm/yr for the two landscape positions. Error bars indicate $\pm \text{SE}$ ($n=52$).

Percent C content for sediments accumulating above the feldspar marker was $5.98 \pm 0.47 \%$ for the transitional landscape and $7.51 \pm 0.88 \%$ for the interior landscape (Figure 2.7). Percent N content for sediment above the feldspar was $0.47 \pm 0.03 \%$ within the transitional and $0.57 \pm 0.05 \%$ within the interior landscape

positions. Sediment samples overlying sedimentation disks had percent C content of $2.47 \pm 0.23 \%$, $2.8 \pm 0.13 \%$, $5.19 \pm 0.02 \%$ for the channel, transitional, and interior landscape positions respectively. Percent N content for the sedimentation data was $0.24 \pm 0.02 \%$, $0.26 \pm 0.01 \%$, and $0.52 \pm 0.02 \%$ (Figure 2.8).

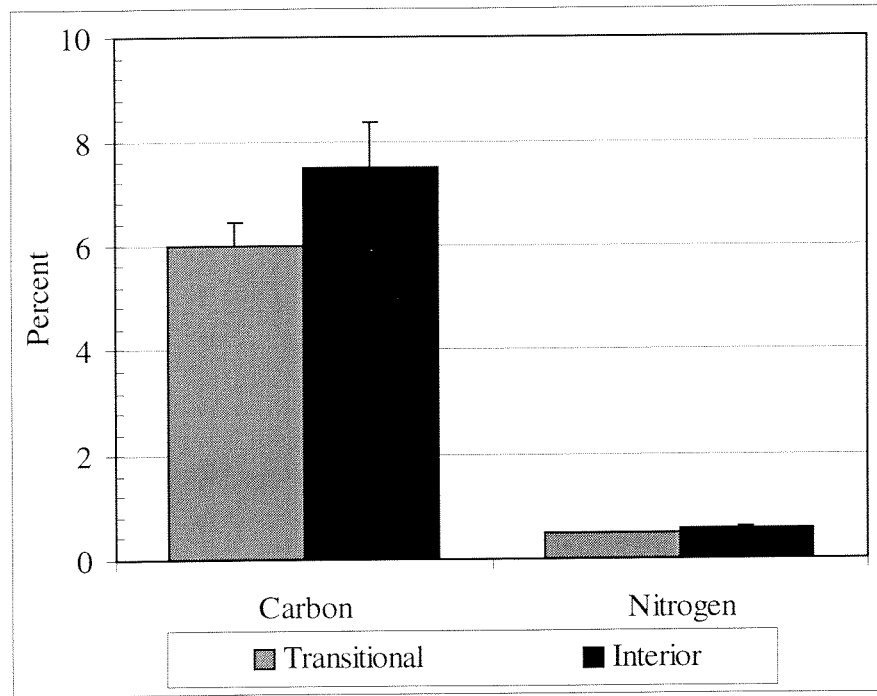


Figure 2.7. Average percent C and N content of sediments accumulated on feldspar markers. Error bars indicate \pm SE (n=52).

Sedimentation Rates and Rainfall Interactions

During the 317 days of sampling, 87.8 cm of rainfall occurred. The greatest amount occurred between the October and December collections and between the February and April collections, 28.6 and 26.3 cm, respectively. A linear regression analysis was performed for the average sediment accumulated per collection versus the amount of rainfall collected during each collection for the three landscape positions: channel, transitional, and interior. There were no significant correlations between the amount of rainfall per collection event and the amount of sediment per

collection event for any of the three landscape positions. The correlations (R^2) for the channel, transitional, and interior landscape were 0.014, 0.038, and 0.267, respectively.

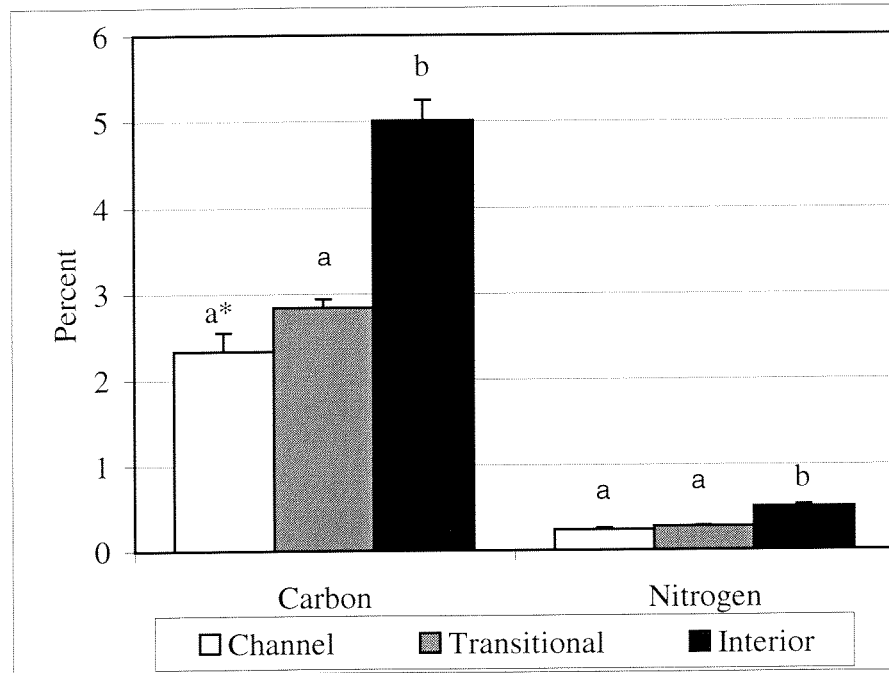


Figure 2.8. Average C and N content of sediments accumulated on sedimentation disks for channel, transitional, and interior landscape positions. Error bars indicate \pm SE ($n=57$, 175 , and 81).

*Treatments with different letters are significantly different at $\alpha = 0.05$.

Sedimentation Disks: Sedimentation Rates

Sediment accretion measurements for the disk method, marker horizon method, and sedimentation rate equation were normalized to per day rates for comparison purposes. Direct measurements of sediment mass accumulation averaged over the 317 days for the sedimentation disk methods within the channel, transitional, and interior landscape positions revealed rates of 23.75 ± 5.43 g/m²/d, 37.11 ± 5.09 g/m²/d, and 27.94 ± 4.65 g/m²/d, respectively (Table 2.1). Tukey's post-hoc test revealed that the interior landscape position was statistically similar to

the channel and to the transitional. However, the channel and transitional landscape positions were statistically different from each other. A Satterthwaite's t-test was performed to compare current rates of accumulation using the feldspar marker horizon data (cm/yr) with historic rates using core data (cm/yr). A p value of 0.0001 identified there was a significant statistical difference in current versus historic sedimentation rates within Bluebonnet Swamp, Louisiana.

Table 2.1. Average sedimentation rates of channel, transitional, and interior landscape positions in Bluebonnet Swamp, Louisiana.

Sedimentation Rate Methods	Landscape Position		
	Channel	Transitional	Interior
Sediment Disk Method (g/m ² /d)	23.75 ± 5.43 (a) [†]	37.11 ± 5.09 (b)	27.94 ± 4.65 (ab)
Feldspar Marker Horizon (g/m ² /d)	-*	27.20 ± 3.64	29.61 ± 2.57
Sedimentation Rate Equation (g/m ² /d)	-*	25.73 ± 3.57	27.71 ± 2.57
Cores (cm/yr)	-**	0.57	0.41
Feldspar Marker Horizon (cm/yr)	-*	2.23 ± 0.063	3.07 ± 0.036

[†]Treatments with different letters are significantly different at $\alpha = 0.05$.

*Feldspar marker horizons were not established within the channel landscapes due to water velocity and channel slope.

**Soil core samples were not taken from the channel landscape position.

Discussion

Core Data: Cs¹³⁷ Analyses

Peak Cs¹³⁷ activity in the Bluebonnet Swamp allowed this study to infer the approximate depth at which the year 1963 occurred (Cahoon and Turner, 1989). The Cs¹³⁷ analysis identifies an average overall sedimentation rate for the past 37 years and cannot identify rate variations due to short-term episodic urbanizing activities. Factors that could have affected sedimentation rates within the landscape positions include various upslope soil disturbances associated with commercial and residential development. The two core extracted provide historic sedimentation rates thus

allowing comparisons to current rates. A statistically significant difference between current and historic sedimentation rates was identified within Bluebonnet Swamp.

This study revealed historic sediment accumulation rates of 0.41 to 0.57 cm/yr for an urban forested wetland for 1963 to 2000 which supports the findings of other forested wetland accretion rates (Boto and Patrick, 1978; Kleiss, 1996; Heimann and Roell, 2000). McIntyre and Naney, (1991) determined an accretion rate of 2.6 cm/yr where the bulk density was 1.3 g/cm^3 (primarily silt sediment) and 1.3 cm/yr where the bulk density was 0.65 g/cm^3 (primarily clay sediment). Bulk density of the two cores for the transitional landscape was $0.5709 \pm 0.150 \text{ g/cm}^3$ and $0.3359 \pm 0.030 \text{ g/cm}^3$ for the interior landscape. Bulk density measurements taken from the soil cores showed an increase with depth (Craft and Casey, 2000; Craft and Richardson, 1998), which may appear as lower sedimentation rates due to compaction (Hupp and Bazemore, 1993; Kleiss, 1996; Heimann and Roell, 2000). My data did not support those findings. Greater sedimentation rates and greater bulk density occurred within the transitional landscape where there was less inundation and greater time in which the soil could compact.

Feldspar Marker Horizons

It is possible that the soil samples collected from the feldspar marker horizon contained more leaf material than the sedimentation disk samples because they were sampled only once (six months after installation) and not approximately every month like the sedimentation disks. Also, within that six-month interval, a greater percentage of leaf material would have decomposed and been able to pass through the 2-mm sieve prior to analysis. This might explain why there was a greater %C in

the feldspar marker horizon sediment than in the sedimentation disk sediment. In addition to Stoke's Law, which states smaller diameter particles take longer to settle out of the water column, organic matter binds more readily to clay particles than sand particles (Boto and Patrick, 1978; Johnston, 1991). Since there was a greater C:N ratio and lower bulk density in the interior landscape, my data supports the conclusion that more organic matter accumulates in that particular portion of the swamp (Puckett, et al., 1993; Poach and Faulkner, 1998). Puckett, et al. (1993) observed higher C:N ratios in dry, infrequently flooded areas where leaf litter accumulated in great quantities, which resembles characteristics of the interior landscape position.

Based on direct depth accumulation of sediment overlying the feldspar marker horizons, analyses determined sedimentation rates between August 2000 and May 2001 of 2.23 ± 0.063 to 3.07 ± 0.036 cm/yr. Using feldspar marker horizons, Heimann and Roell (2000) determined an annual sedimentation rate within an agricultural basin to be about 1 cm/yr. Johnston (1991) found that average rates were 0.69 cm/yr for mineral soil wetlands. Hupp and Bazemore (1993) observed a yearly rate of 0.24 to 0.26 (cm/yr) for sediment accumulating in a forested wetland. Craft and Casey (2000) observed a much lower accretion rate (0.08 cm/yr) for a forested depressional wetland; however, their study site has not been influenced by anthropogenic activities since the early 1930s and there was a buffer zone located between the upslope and interior portions of the wetland. The study site of this experiment contained higher sedimentation rates than other forested wetlands;

however, it is located in an area where 5% of the watershed became urbanized to 54% between the years of 1962 and 2001 (Dr. Mitchell, personal communication).

Sedimentation Rates and Rainfall Interactions

No significant correlations were observed for any of the landscape positions with the amount of rainfall per collection event; therefore, the data and linear correlation is not sufficient in being able to predict the sedimentation rate given a rainfall amount. Rainfall intensity and duration measurements taken at the study location, soil erosivity, and channel slope would have allowed for a more thorough investigation of the relationship of sedimentation rates due to rainfall amounts (Puckett, et al., 1993).

Channel Landscape Position

The sedimentation rate in the channel landscape position was determined by the sedimentation disk method. Due to high water velocity and a narrow channel width, feldspar horizon marker use was precluded. This landscape was an area where little sedimentation accumulation was expected. Hupp and Bazemore (1993) observed lower rates of sedimentation occurring on higher topographically-positioned sites where the stream power was the greatest and hydroperiod was the least. Boto and Patrick (1978) observed that a decrease in stream velocity promoted suspended sediments to fallout. Puckett, et al. (1993) also observed increases in sediment, particularly silt-clay sediment, with increasing distances downstream resulting from a decrease in stream velocity. Heimann and Roell (2000), on the other hand, determined channelization might have increased sedimentation deposition along the basin of their study site. The characteristics of sediment influx

and stream qualities in this study site reflect those findings of Hupp and Bazemore (1993), Boto and Patrick (1978), and Puckett, et al. (1993).

Transitional Landscape Position

There was close agreement in sedimentation rate methods ranging from 25.73 ± 3.57 to 37.11 ± 5.09 g/m²/d for the transitional landscape position for the various methods with the sedimentation disk method yielding the greatest rate of accumulation. The transitional landscapes represented areas of decreased flow velocity compared with channel landscapes, which could have resulted in an increase of sedimentation (Hupp and Bazemore, 1993). As the higher water velocity carried the particles from the channel landscape into the interior landscape position, the heaviest particles were able to fall out of the water column prior to reaching the interior of the swamp. Heavier sediment particles will cause a greater bulk density, and particles, like sands and silts, contain less clay content and less organic material. The bulk density and percent carbon data gathered in this study could explain why the greatest sedimentation rate occurred within the transitional landscape position.

Interior Landscape Position

The accumulation rates ranged from 27.71 ± 2.57 to 27.94 ± 4.65 g/m²/d. Hupp and Bazemore (1993) found higher depositional rates were located in areas where ponding occurred where the area is flooded more frequently and for longer periods of time. Phipps, et al. (1995) also found that frequent inundation caused greater sedimentation rates due to an increase in exposure time to a sediment source. Kleiss (1996) concluded that suspended sediment was retained in the area where the water had the longest retention time. Although retention time was not directly

measured in this study, ponding frequency was observed throughout the study. Visual observations identified the interior landscape inundated with water more frequently than the other two landscapes; however, greater retention time of sediments within the water column of that landscape area did not lead to greater sedimentation rates (Hupp and Bazemore, 1993).

Visual observations of the water flow throughout the landscape positions identified the greatest flow rate in the channel landscape and least in the interior landscape. Since the slope and water flow rate decreased within the transitional landscape toward the interior of the swamp, heavier sediment particles within the water column were able to settle out prior to reaching the interior landscape.

Conclusions

Sedimentation rates for Bluebonnet Swamp measured by Cs¹³⁷ analysis, feldspar marker horizons, and sedimentation disks were comparable to those reported for depressional, freshwater, inland swamps (Johnston, 1991; Hupp and Bazemore, 1993; Kleiss, 1996; Heimann and Roell, 2000). Sedimentation rates measured from sediment accreting vertically over feldspar marker horizons shows current sedimentation rates are significantly higher than historic rates measured with soil cores. Within Bluebonnet Swamp, my study shows similar sedimentation rates by using the sedimentation disks and the sedimentation rate equation (Downer, et al., 1995; Lowrance, et al., 1988), utilizing data gathered from the feldspar marker horizons. Therefore, the use of sedimentation disks and feldspar marker horizons are effective tools in establishing sedimentation rates within Bluebonnet Swamp. The average sedimentation rate for all three landscape positions for the sedimentation

disk method, feldspar marker horizon, and sedimentation rate equation methods for July 2000 through May 2001 was $28 \text{ g/m}^2/\text{d}$. By approximating the storage capacity of Bluebonnet Swamp is half the total acreage (20 hectares), the total retention capacity of the swamp for sediments and pollutants is around two billion $\text{g/m}^2/\text{d}$. With sediment accumulation occurring within Bluebonnet Swamp, downstream receiving water bodies, such as Bayou Manchac, are receiving less sediment and pollutants over time. The pollutant retention function of Bluebonnet Swamp effectively maintains and improves downstream water quality for flora and fauna habitats, as well as, agricultural, industrial, and drinking water purposes.

CHAPTER 3: METAL RETENTION IN AN URBAN SWAMP

Introduction

Wetlands benefit ecosystems by functioning as water storage basins, sinks for sediment and nutrients, and habitat for flora and fauna. More specifically, depressional wetlands function hydrogeomorphically by decreasing total suspended solids, metal concentrations, and excess nutrients from entering downstream water bodies (Boto and Patrick, 1978; Johnston, et al., 1984; Preston and Bedford, 1988; Coreil, 1994; Brinson, 1995; Craft and Casey, 2000).

Hupp and Bazemore (1993) found higher sediment retention rates in areas of ponding due frequent flooding and longer water retention time. Phipps, et al. (1995) also found that frequent inundation caused greater sedimentation rates due to an increase in exposure time to a sediment source. Kleiss (1996) concluded that suspended sediment was retained in areas where water had the longest retention time. Settling velocity of smaller diameter particles, like clays, take longer to settle out of the water column (Miller and Donahue, 1995: 97). Areas of high organic matter can occur in oxidized, high clay content soils, like soils in a depressional wetland where inundation causes a decrease in organic matter decomposition.

Sediment influx and retention within a wetland can be a source of nutrients and contaminants. Urbanization in a surrounding watershed increases erosion and sediment transport. Landscape position and gradient, ground surface roughness, vegetative cover, water velocity, and size and shape of a storage basin area influence sediment influx and retention (Hupp, et al., 1993; Phipps, et al., 1995).

Clay sediment particles have a greater surface area and a greater cation exchange capacity than sand and silt; thereby, retaining more contaminants. Metal retention is affected by silt and clay soil content (Puckett, et al., 1993), pH, and redox conditions (Boto and Patrick, 1978). Soil sorption processes allow metals to be temporarily or permanently removed through soil burial causing certain areas to become sinks if the net output of metals is less than the net input (Puckett, et al., 1993). Temporary or permanent removal pathways include plant uptake, adsorption, and precipitation processes. Metal storage is also dependent on the type and volume of sediment entering the wetland, metal speciation, and influx method (Gambrell, et al., 1983). Before being eliminated in the 1970s, lead was a gasoline additive to boost the octane quality of fuel. Influenced by traffic density, road width, location of the source, and ventilation, lead content in urban wetland soils can occur through atmospheric fallout or through sorption onto soil particles retained in the wetland (Hutchinson and Meema, 1987).

Research Objectives

The objectives of this study were to quantify metal retention rates within an urban wetland and to determine if metal retention within the wetland is being affected by urbanization within the watershed.

Materials and Methods

Study Area

Bluebonnet Swamp was chosen because of its location in a rapidly developing urban watershed in Baton Rouge, Louisiana (Figure 3.1). While the watershed is approximately 50,586 ha (125,000 ac), Bluebonnet Swamp covers only

42 ha (105 ac). The Y-shaped swamp is approximately 1.61 km long and 183 m wide (James Mitchell, personal communication). A 6-meter drop in elevation exists from the escarpment to the cypress-water tupelo (*Taxodium distichum*-*Nyssa aquatica*) swamp.

Sediment and Metal Sampling

Six distinct inflow points with erosional channels were identified within Bluebonnet Swamp (Figure 3.1). These erosional channels carry upland runoff into low-slope transitional areas dominated by boxelder (*Acer negundo*), sweetgum (*Liquidambar styraciflua*), and American elm (*Ulmus ameicanus*), and to interior/depressional areas dominated by cypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*), and sugarberry (*Celtis laevigata*). Stratified into channel, transitional, and interior landscape positions, the sites for each stratum were randomly selected. Replicated sedimentation disks and feldspar marker horizons were used to measure current sedimentation rates within each stratum.

The channel landscape positions were located in erosional drainage channels entering Bluebonnet Swamp. The channels contained sandy soils and had little to no vegetation within them. Three replicated disks were established within each channel. Transitional landscapes, having contained silt loam textured soil, had slopes less than that of the erosional channels and greater than that of the interior areas. Little topographical relief, and Fausse (silty clay loam) soils characterized the interior/depressional landscapes (USDA Soil Survey Staff, 1968). Three replicated plots of six disks were installed within the transitional and interior landscape areas.

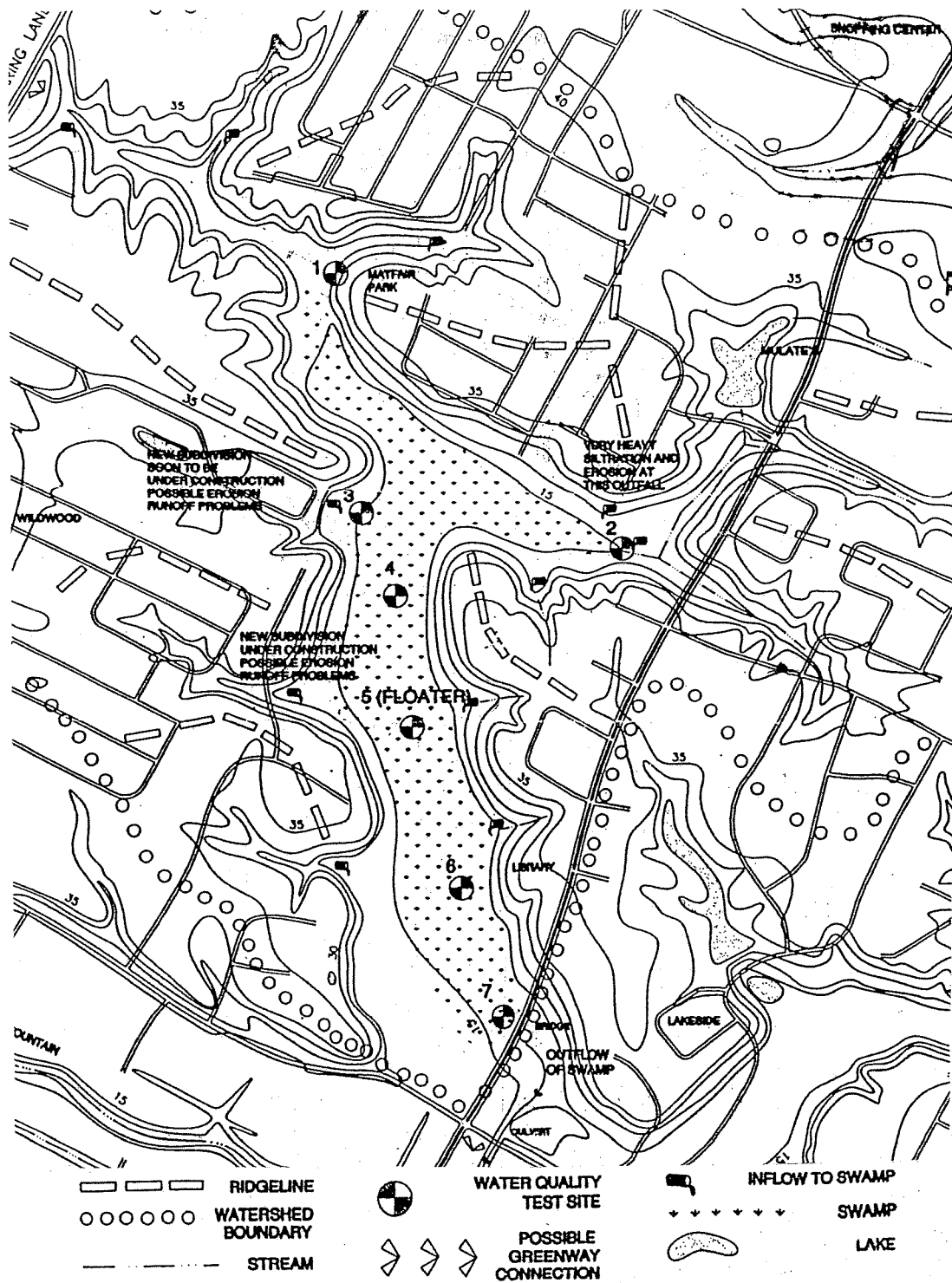


Figure 3.1. Point source inflow locations into Bluebonnet Swamp, Baton Rouge, Louisiana, USA. Map source is BREC Planning and Engineering Department.

The soils found along the terraces of three sides of the swamp are Terrace Escarpment soils (USDA Soil Survey Staff, 1968). These terraces are highly erodible and are often dissected by ravines and drainageways. The southwest side of the swamp has Waverly-Falaya silt loams, overflow which are poorly drained and frequently flooded. The outer perimeter of the swamp is comprised of primarily two types of soils, which are Calhoun silt loam and Oliver silt loam, 0-1 percent slopes. These two soils have slow runoff and slow permeability characteristics.

Louisiana receives more than four inches of rain each month, except for September and October, and has an average annual rainfall of 139 cm (USDA Soil Survey Staff, 1968). Daily rainfall values were collected from a Louisiana Office of State Climatology location a few miles south of Bluebonnet Swamp. Because the wetland is located in a topographic depression, the water becomes centralized in the interior portion of the swamp, which then drains into Bayou Fountain located south of the swamp.

Each disk consisted of a 12.7 cm diameter plexiglass disk with a hole drilled in the center (Kleiss, 1996; Heimann and Roell, 2000). Non-galvanized, 15.3 cm long nails were used to anchor the disk. Preparation of the sites for sedimentation disks began by scraping the soil surface to a depth equal to the thickness of the plexiglass disk (0.318 cm). Each disk was placed, on average, 20 cm apart. Three disks were placed in one row and three in another row just downstream. Depending on space within each designated plot, the two rows were either placed offset from one another or directly behind one another. The distance between the two rows (measuring from the perimeter of the two disks) was on average 15 cm.

Sample Collection

For metal analysis of sediment accumulating in Bluebonnet Swamp, plexiglass disks were used to retain sediment. Every thirty days, or after a rain event, each sediment disk was gently lifted and trimmed with scissors to remove any leaf matter extending over the edge of the disk. A putty knife was used to remove recently accumulated sediment from the disk into a polyethylene bag. Any remaining sediment was rinsed with deionized water into a polyethylene bag and the disk was then replaced in its original position.

Soil collection also occurred through the use of feldspar marker horizons. Retrieval of the sediment samples from the feldspar marker positions began by removing twigs and leaves from the soil surface. Six separate 30.5 cm by 30.5 cm square feldspar marker positions were located at each site. Each feldspar position was dug with a shovel to a depth of 5 cm. The feldspar clay was used to fill the hole and was smoothed flush with the soil surface. A hollow, clear plexiglass tube (10.2 wide and 10 cm long) was twisted into the ground. Where the ground was dry and hard, a piece of plywood and rubber mallet was used to gently hammer the tube into the ground until one half-inch remained above the ground surface. Each tube was dug out of the ground with a spade and placed in a polyethylene bag. All feldspar pots were installed on August 24, 2000 and later sampled on May 21, 2001.

Sample Analysis

To determine a mass value of sediment for each site, the soil was removed from the bags and screened through a 2-mm sieve. Each bag was rinsed several times with deionized water until all visible sediment was retrieved. All material,

such as leaves and twigs, greater than 2-mm was discarded. The sieved soil was placed into beakers and dried at 110°C for 24 hours, weighed, and ground with a mortar and pestle to a fine powder.

To determine a mass value of sediment over the feldspar marker horizon, soil was removed by gently scraping the soil surface with a putty knife until reaching the surface of the feldspar material. Samples were then placed in beakers, dried in an oven at 100°C for 24 hours, and immediately weighed. The soil matter was then ground using a mortar and pestle to a fine powder and stored in 250-ml plastic bottles until analyzed. For determination of carbon and nitrogen for sediment samples of the sedimentation disk and feldspar marker horizons, ten milligrams was weighed for each composite sample and was tested using a Perkin and Elmer 2400 CHN elemental analyzer.

Cesium¹³⁷ analysis was accomplished by retrieving two cores, one from the interior and one from the transitional landscape positions, using thin-walled aluminum tubes (DeLaune, et al., 1978; Cahoon and Turner, 1989). The tube was twisted into the ground, pulled out, and then capped at both ends. The maximum depth at which the transitional and interior soil cores were taken was 97 and 56 cm, respectively. Two-centimeter sections were cut for the entire length of the core and dried at 110°C for 24 hours. Each section was ground using a mortar and pestle and was passed through a 2-mm mesh sieve. The sieved sample was analyzed for Cs¹³⁷ concentrations using a Lithium-based Germanium gamma spectroscopy system. To calculate vertical accretion per year, the depth at which the maximum activity of Cs¹³⁷ occurs is divided into the number of years between the sampling time and

1963. The maximum activity of Cs¹³⁷ has been established to be the year 1963 (Ritchie, et al., 1974; DeLaune, et al., 1978; Cahoon and Turner, 1989).

Current metal concentrations were determined for sedimentation disk samples by compositing and homogenizing the six sediment disks at each subplot (three per landscape position) prior to metal analysis. Homogenization also occurred for the feldspar marker horizon sediment samples within each site. Soil core samples were analyzed for metals per 2-cm increment. Sediment samples were digested in concentrated nitric acid, filtered through No. 42 Whatman filters, and analyzed for Pb, Cd, Cr, Cu, Zn, Ni, P and Al using Jarrel-Ash Model #855 inductively coupled, argon-plasma emission spectroscopy, calibrated before each use (Plumb, 1981).

Aluminum Normalization

Because it is difficult to establish whether contaminant concentrations are “above normal,” a normalization procedure will help establish baseline sediment metal concentrations. Normalization with Al has been used successfully to evaluate soil contamination (Pardue, et al., 1992; Summers, et al., 1996; Tam and Yao, 1998). To compensate for the effects of increasing metal absorption with increasing clay content, each metal concentration was divided by the Al concentration in that sample. Background metal concentrations (μg/g) were developed for each analyte by averaging concentrations below the Cs¹³⁷ 1963 peak to identify anthropogenic influences.

Pre-1963 versus Post-1963 Metal Concentrations

Pre-1963 metal (μg/g)/(%Al) ratios were determined by averaging those increments deeper than the peak Cs¹³⁷. For the interior core, that corresponded with

15 cm below ground surface and 21 cm for the transitional core. Pre-1963 represents background sediment metal concentrations during times when little anthropogenic activity occurred within the Bluebonnet Swamp watershed. Post-1963 represents that time period where urbanization began and anthropogenic activities increased. Such anthropogenic activities included the establishment of residences to the north and west of the swamp, as well as road development bordering the eastern side of the swamp. Businesses also border the eastern portion of Bluebonnet Swamp. Sediment metal concentrations from the sedimentation disks and feldspar marker horizons were compared with pre-1963 background levels to determine if concentrations have increased with time. Changes in impervious surfaces, resulting from urbanization, and changes in forested, pasture, and water acreages having occurred from 1963-2001 were quantified through spatial analysis using ArcInfo (James Mitchell, personal communication).

Statistical Analysis

A Pearson's correlation analysis was performed for analyte concentrations and depth. Each analyte concentration was averaged for each 2-cm increment of the two cores extracted from Bluebonnet Swamp. Analysis of variance and Tukey's post-hoc test for comparisons was used to identify differences in the three landscape positions (channel, transitional, and interior). A T-test was used to compare pre- and post-1963 metal concentrations. An alpha level of 0.05 was used as the level of significance for all analysis performed. All statistical analyses were performed using the statistical package SAS (SAS, 1985).

Results

While trace and toxic metal concentrations can vary greatly in uncontaminated soils with changing soil texture, an increase in metal concentration normalized to Al may be an indicator of contamination. Baseline concentrations, for areas predetermined as potentially uncontaminated, are determined by plotting metal concentration versus %Al, creating a linear regression line for the data, and establishing 95% confidence level intervals for the regression line. Data points (metal concentrations) plotted above the upper confidence interval are suspected to be contaminated (Pardue, et al., 1992; Daskalakis and O'Connor, 1995; Summers, et al., 1996; Rice, 1999). Aluminum normalization (establishing a ratio by dividing a metal concentration by percent Al) was performed on each analyte of the sedimentation disk, feldspar marker horizon, and core data.

Core Data: Correlation Analysis

A Pearson's correlation analysis was performed for sediment metal concentrations and depth in which correlation coefficients and p values are reported (Table 3.1). Low Pearson correlation coefficients occurred for the core soils indicating a low degree of correlation between the metals analyzed, and between the metals analyzed with depth. Negative Pearson's correlation coefficients for Pb, Cu, Zn, Ni, and P demonstrate a decrease in metal concentration with depth. Positive correlation coefficients existed for Cd, Cr, and Al with depth. Calculated p values for Cd ($p = 0.0017$), Cr ($p = 0.0033$), Cu ($p = 0.0001$), Zn (0.0067), Ni ($p = 0.0024$), and P ($p = 0.0018$) indicates there are statistical correlations between sediment metal concentrations and depth.

Table 3.1. Pearson's Correlation Coefficients and p values for metal concentration ($\mu\text{g/g}$) versus depth for soil cores within Bluebonnet Swamp (n=35).

	Depth	Pb	Cd	Cr	Cu	Zn	Ni	P	Al
Depth	1.000*	-0.187	0.512	0.483	-0.847	-0.450	-0.497	-0.509	0.280
	0.00**	0.2813	0.0017	0.0033	0.0001	0.0067	0.0024	0.0018	0.1038
Pb		1.000	0.428	0.131	0.451	-0.070	0.568	0.030	0.142
		0.0000	0.0103	0.4522	0.0066	0.6898	0.0004	0.8645	0.4160
Cd			1.000	0.165	0.836	-0.200	0.775	-0.181	-0.518
			0.0000	0.3443	0.0001	0.2484	0.0001	0.2975	0.0014
Cr				1.000	-0.146	-0.343	0.347	-0.585	-0.005
				0.0000	0.4025	0.0436	0.0410	0.0002	0.9761
Cu					1.000	0.189	0.796	0.246	-0.307
					0.0000	0.2764	0.0001	0.1551	0.0725
Zn						1.000	0.105	0.435	0.151
						0.0000	0.5465	0.0091	0.3857
Ni							1.000	0.006	-0.039
							0.0000	0.9748	0.8227
P								1.000	0.288
								0.0000	0.0935
Al									1.000

*Pearson's Correlation Coefficient; **p value.

Core Data: Aluminum Normalized Correlation Analysis

Because metal concentrations vary with soil texture, the analytes were normalized with %Al then plotted with depth. Core #1 extracted from the interior landscape position depicts little to no change with depth for Cd, Cr, Cu, and Ni (Figures 3.2, 3.3). Lead concentrations increase around 1963 (the year of peak Cs¹³⁷ activity) decrease for several years beginning at the 12-14 cm deep increment, and then an increase again around the 4-6 cm increment to current metal concentrations. Zinc and P also increase around 1963 with concentrations decreasing around the 6-8 cm increment and then increasing to current concentrations. Core #2 depicts similar trends for Cd and Cr as Core #1; however, Pb, Cu, Zn, Ni, and P concentrations show gradual increases over time (Figure 3.4, 3.5).

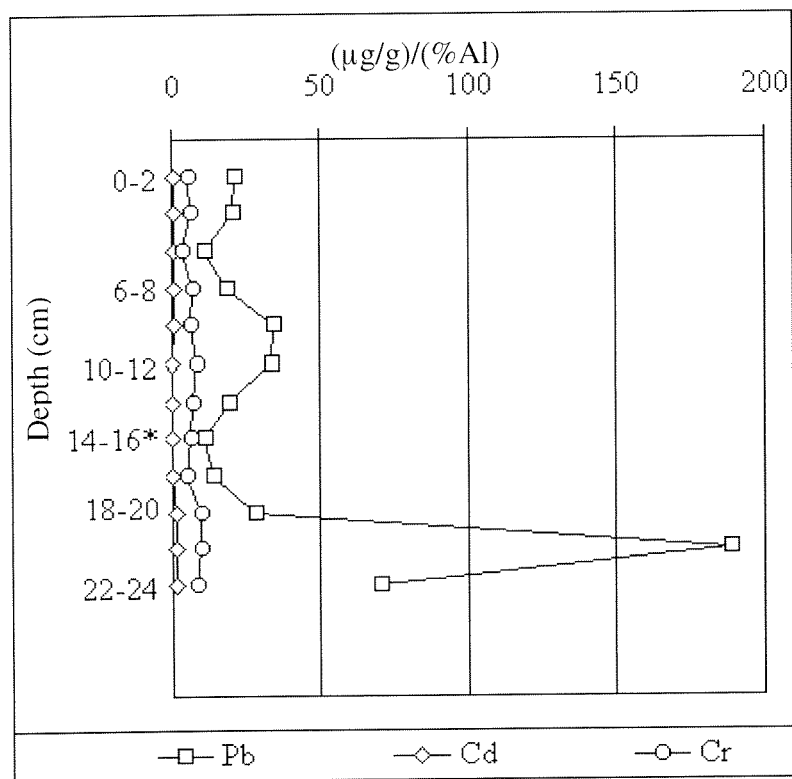


Figure 3.2. Average Pb, Cd, and Cr concentration ($\mu\text{g/g}$)/%Al ratio for Core #1.
 *Peak Cs^{137} activity occurred at 15 cm.

Core Data: Pre- and Post-1963 Metal Concentrations

Analysis of variance indicates statistically significant differences between pre- and post-1963 sediment metal ($\mu\text{g/g}$)/%Al ratios for Cd, Cu, Zn, Ni, and P, but not for Pb and Cr (Table 3.2). Post-1963 metal ($\mu\text{g/g}$)/%Al ratios were statistically greater in recently accumulating sediment than pre-1963 sub-surface sediment for all analytes except Cr. There were no statistical differences in pre- and post-1963 Pb ($\mu\text{g/g}$)/%Al ratio. Although statistics were not performed between the pre-1963 ratios obtained from Bluebonnet Swamp and Louisiana coastal sediment ratios

obtained by Pardue, et al., (1992), the analyte/%Al ratios Bluebonnet Swamp sediment are greater for Pb and Cr.

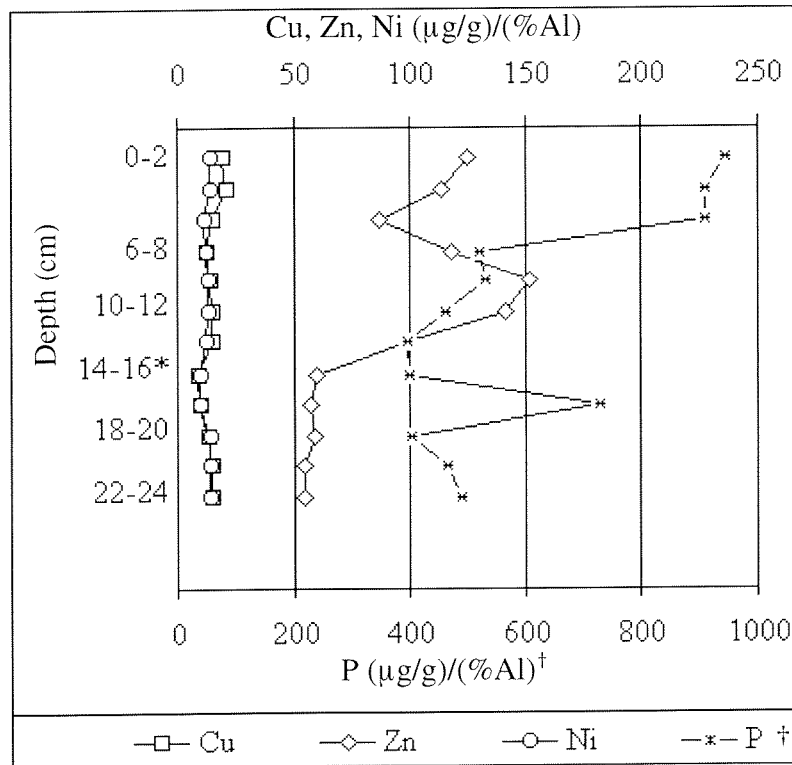


Figure 3.3. Average Cu, Zn, Ni, and P concentration ($\mu\text{g/g}/\% \text{Al}$) ratio for Core #1. \dagger P is plotted on the secondary y-axis; *Peak Cs^{137} activity occurred at 15 cm.

Feldspar Marker Horizons: Concentrations per Landscape

ANOVA and Tukey's post hoc tests were performed on metal concentrations ($\mu\text{g/g}$) for the interior and transitional landscapes. Statistically significant concentration ($\mu\text{g/g}$) differences occurred between the two landscapes for Pb, Cr, Ni, and Al; however, there were no significant differences for Cu, Zn, Cd, and P (Figure 3.6, 3.7; Table 3.3).

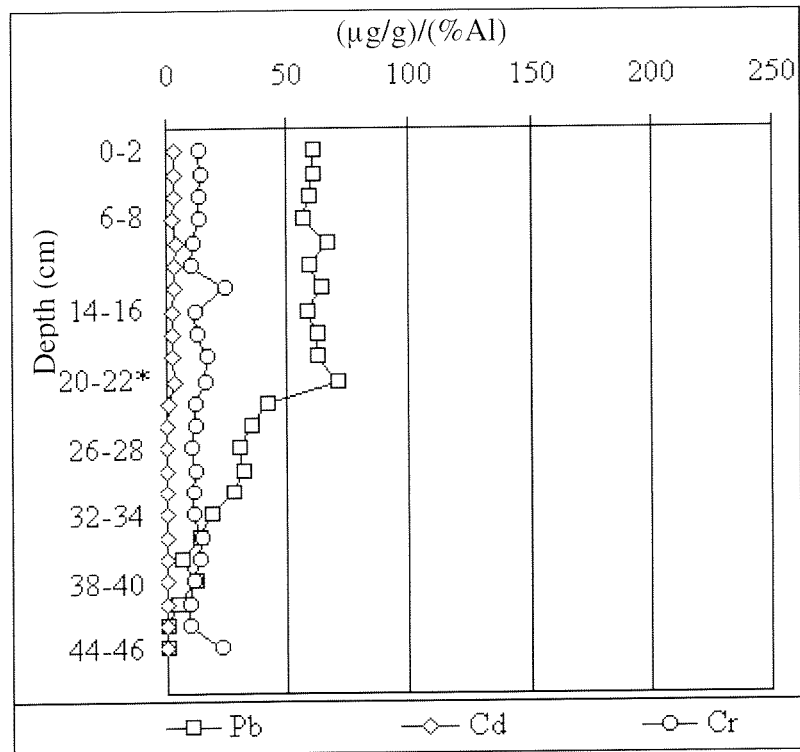


Figure 3.4. Average Pb, Cd, and Cr concentration ($\mu\text{g/g}$)/ $\% \text{Al}$ ratio for Core #2.
*Peak Cs^{137} occurred between 21 cm.

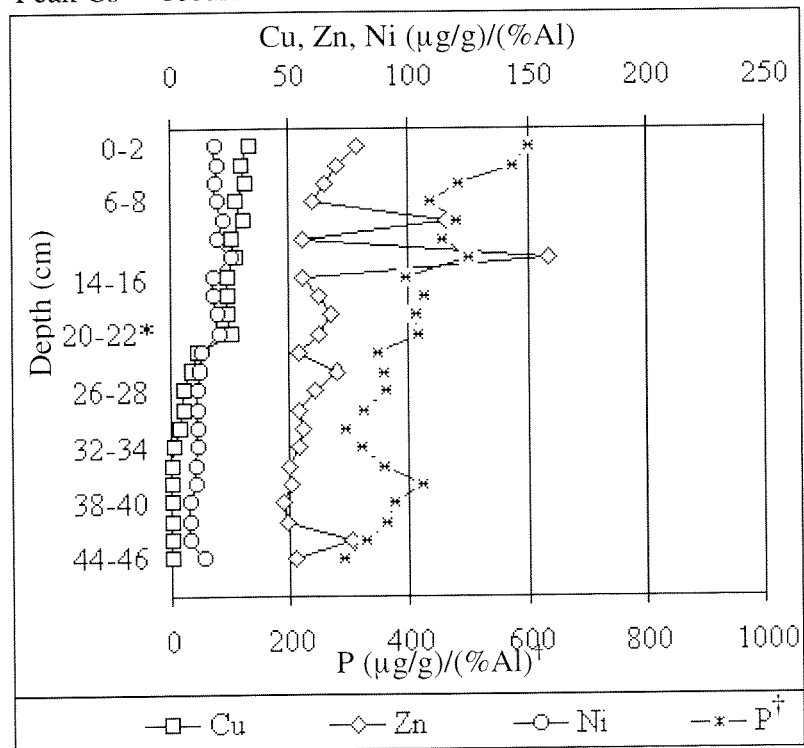


Figure 3.5. Average Cu, Zn, Ni, and P concentration ($\mu\text{g/g}$)/ $\% \text{Al}$ ratio for Core #2.
†P is plotted on the secondary y-axis; *Peak Cs^{137} activity occurred at 21 cm.

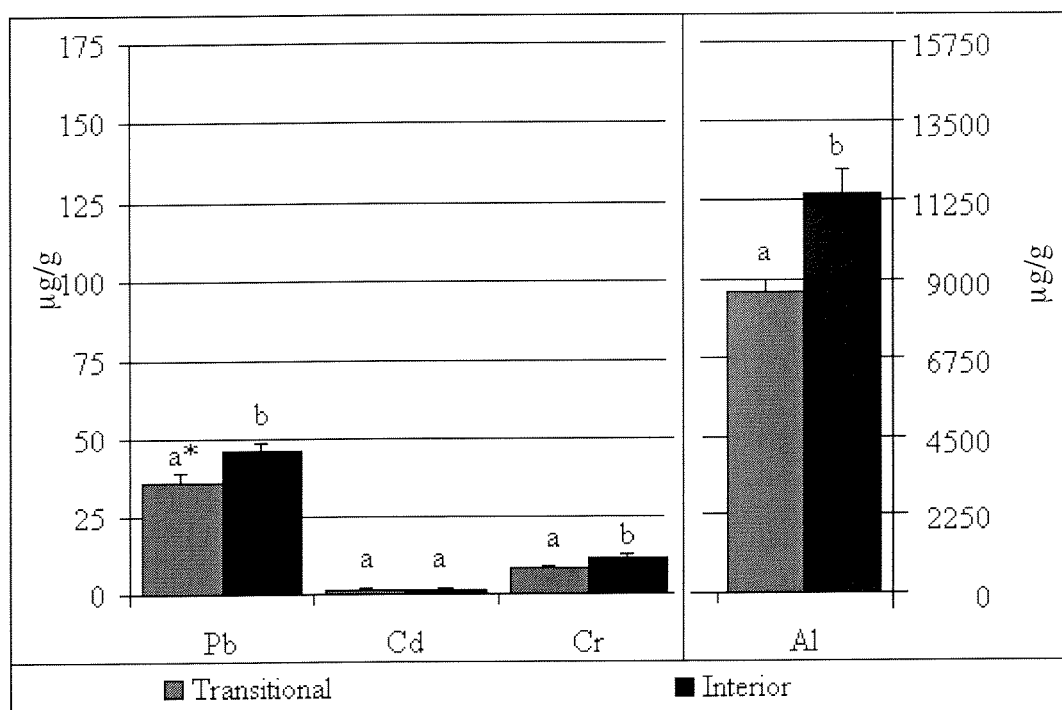


Figure 3.6. Average analyte concentration ($\mu\text{g/g}$) of the feldspar marker soil samples from each landscape position for Pb, Cd, Cr, and Al.

*Treatments with different letters are significantly different at $\alpha = 0.05$.

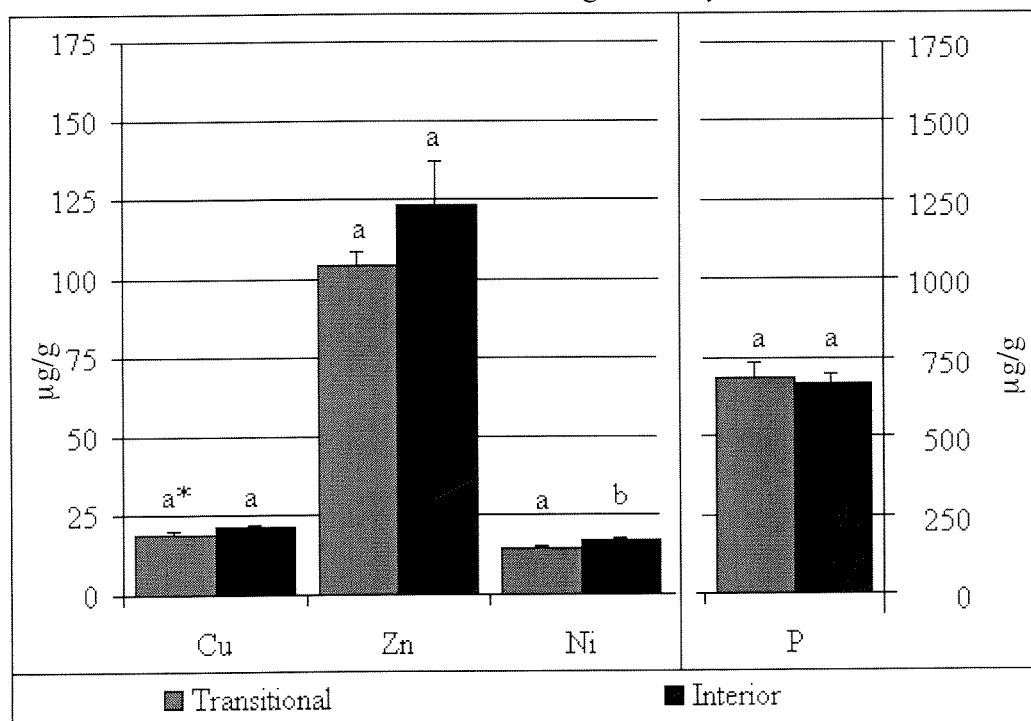


Figure 3.7. Average analyte concentration ($\mu\text{g/g}$) of the feldspar marker soil samples from each landscape position for Cu, Zn, Ni, and P.

*Treatments with different letters are significantly different at $\alpha = 0.05$.

Table 3.2. Pre- and post-1963 analyte ($\mu\text{g/g}$)/(%Al) ratios for core sediment and background ratios for coastal Louisiana sediment.

Analyte	Background Ratios		Core Data	
	LA Coastal Sediment*	Pre-1963 Sediment	Post-1963 Sediment	
Pb	29.7	32.5 ± 45 (a)	45.1 ± 20 (a)	
Cd	1.26	0.315 ± 0.51 (a)	2.00 ± 1.4 (b)	
Cr	6.76	11.0 ± 3.8 (a)	10.7 ± 5.0 (a)	
Cu	N/A**	5.32 ± 5.6 (a)	22.7 ± 6.8 (b)	
Zn	N/A	56.2 ± 7.5 (a)	95.7 ± 35 (b)	
Ni	N/A	11.1 ± 2.2 (a)	17.0 ± 4.1 (b)	
P	N/A	389 ± 106 (a)	555 ± 184 (b)	

*Data from Pardue, et al. (1992); **Not available (N/A).

Feldspar Marker Horizons: Aluminum Normalized

To reduce soil texture effects on concentration, each analyte was normalized with %Al. When Al normalized, ANOVA tests determined statistically significant differences in Cu and Ni ($\mu\text{g/g}$)/(%Al) ratios between the transitional and interior landscape positions (Table 3.4). There were no significant differences in Pb, Cd, Cr, Zn, and P ($\mu\text{g/g}$)/(%Al) ratios for the two landscape positions.

Table 3.3. Average analyte concentrations ($\mu\text{g/g}$) for the feldspar marker horizons within the transitional and interior landscapes in Bluebonnet Swamp, Louisiana (n=34, 18), respectively.

Analyte	Transitional	Interior
Pb	36.4 ± 2.7 (a*)	46.5 ± 4.3 (b)
Cd	1.36 ± 0.05 (a)	1.52 ± 0.06 (a)
Cr	8.43 ± 0.65 (a)	11.3 ± 1.3 (b)
Cu	19.1 ± 0.63 (a)	21.5 ± 1.5 (a)
Zn	104 ± 9.7 (a)	123 ± 18 (a)
Ni	14.4 ± 0.47 (a)	16.9 ± 0.78 (b)
P	682 ± 51 (a)	665 ± 34 (a)
Al	$8,649 \pm 310$ (a)	$11,430 \pm 670$ (b)

*Treatments with different letters are significantly different at $\alpha = 0.05$.

Sedimentation Disks: Concentrations per Landscape

ANOVA test revealed Pb, Cd, Cu, Zn, Ni, P, and Al ($\mu\text{g/g}$) were statistically different in the interior landscape versus the other two landscape positions for the sedimentation disk data (Table 3.5; Figure 3.8, 3.9). Metal ($\mu\text{g/g}$)/%Al ratios were significantly different between the channel and transitional landscapes for Ni and Al. The interior landscape position contained the greatest analyte concentrations followed by decreasing concentrations in the transitional and channel landscapes.

Table 3.4. Average Al-normalized concentration ($\mu\text{g/g}$)/(%Al) for each analyte of the feldspar marker horizons for the transitional and interior landscapes in Bluebonnet Swamp, Louisiana (n=34, 18), respectively.

Analyte/%Al	Transitional	Interior
Pb	45.3 ± 4.9 (a*)	39.2 ± 2.0 (a)
Cd	1.61 ± 0.066 (a)	1.36 ± 0.05 (a)
Cr	10.0 ± 0.69 (a)	9.64 ± 0.83 (a)
Cu	22.7 ± 0.80 (a)	18.8 ± 0.77 (b)
Zn	120.4 ± 9.1 (a)	106 ± 15 (a)
Ni	17.0 ± 0.54 (a)	15.1 ± 0.60 (b)
P	777 ± 47 (a)	589 ± 14 (a)

*Treatments with different letters are significantly different at $\alpha = 0.05$.

Table 3.5. Average analyte concentration ($\mu\text{g/g}$) for each landscape position for the sediment disk samples (n=313) in Bluebonnet Swamp, Louisiana.

Analyte	Channel	Transitional	Interior
Pb	25.3 ± 1.8 (a*)	32.6 ± 1.8 (a)	50.0 ± 2.3 (b)
Cd	1.18 ± 0.09 (a)	1.45 ± 0.08 (a)	1.98 ± 0.09 (b)
Cr	8.06 ± 7.1 (a)	11.6 ± 1.0 (ab)	15.8 ± 1.4 (b)
Cu	23.3 ± 1.7 (a)	24.5 ± 1.3 (a)	31.8 ± 0.77 (b)
Zn	70.7 ± 4.8 (a)	89.3 ± 4.5 (a)	161.1 ± 14 (b)
Ni	11.6 ± 3.7 (a)	14.2 ± 0.58 (b)	20.45 ± 0.60 (c)
P	583 ± 40 (a)	676 ± 32 (a)	$1,462 \pm 67$ (b)
Al	$6,319 \pm 240$ (a)	$7,622 \pm 170$ (b)	$13,751 \pm 300$ (c)

*Treatments with different letters are significantly different at $\alpha = 0.05$.

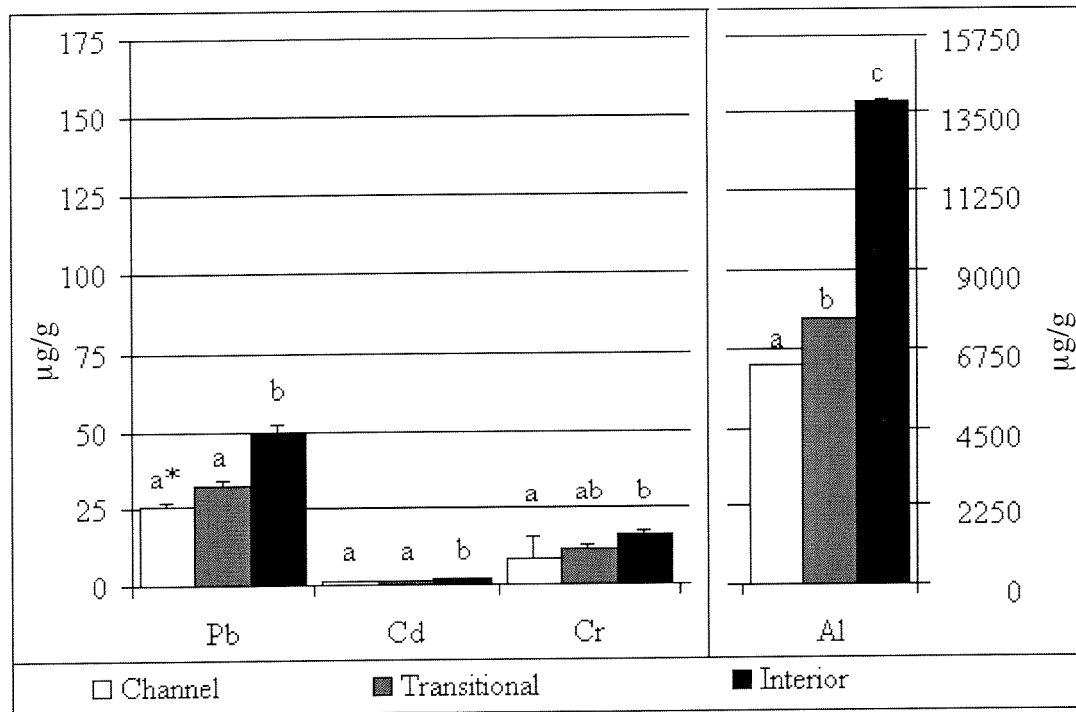


Figure 3.8. Average analyte concentration ($\mu\text{g/g}$) of the sediment disk soil samples from each landscape position for Pb, Cd, Cr, and Al.

*Treatments with different letters are significantly different at $\alpha = 0.05$.

Sedimentation Disks: Aluminum Normalized

When %Al normalized, an ANOVA test determined that none of the analytes were significantly different in all the three landscape positions (Table 3.6). The channel and transitional landscape metal ($\mu\text{g/g}/(\%\text{Al})$) ratios were statistically the same for all analytes; whereas, the channel and interior landscapes had significant differences for the Cd, Cu, Ni, and P ratios. Transitional landscape ratios were statistically different from the interior landscape ratios for Pb, Cd, Cu, Ni, and P.

Copper and Zn ($\mu\text{g/g}/(\%\text{Al})$) ratios were greatest in the channel landscapes. Metal/%Al ratios were greatest in the transitional landscape for Pb, Cd, Cr, and Ni. Phosphorus ($\mu\text{g/g}/(\%\text{Al})$) ratio was the greatest in the interior landscape.

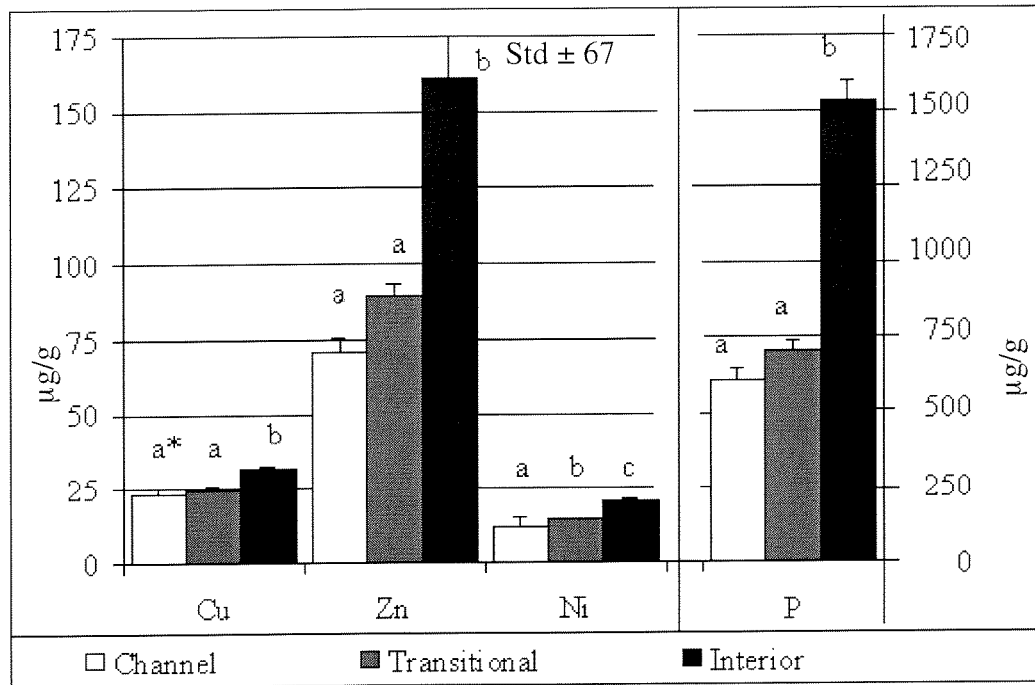


Figure 3.9. Average analyte concentration ($\mu\text{g/g}$) of the sediment disk soil samples from each landscape position for Cu, Zn, Ni, and P.

*Treatments with different letters are significantly different at $\alpha = 0.05$.

Table 3.6. Average Al-normalized concentration ($\mu\text{g/g}/(\%\text{Al})$) ratio of each analyte for the sedimentation disk data for each landscape position in Bluebonnet Swamp, Louisiana (n=313)

Analyte	Channel	Transitional	Interior
Pb	38.8 ± 3.7 (ab)*	44.8 ± 4.7 (a)	35.9 ± 1.2 (b)
Cd	1.68 ± 0.14 (ab)	1.95 ± 0.17 (b)	1.44 ± 0.05 (c)
Cr	12.5 ± 2.1 (a)	15.6 ± 2.2 (ab)	11.0 ± 0.79 (ac)
Cu	36.0 ± 3.9 (a)	33.9 ± 3.0 (ab)	23.8 ± 0.69 (c)
Zn	122 ± 17 (a)	117 ± 7.8 (a)	115 ± 6.3 (a)
Ni	18.6 ± 1.2 (a)	19.2 ± 1.2 (ab)	15.0 ± 0.28 (c)
P	961 ± 97 (a)	840 ± 40 (ab)	$1,100 \pm 54$ (c)

*Treatments with different letters are significantly different at $\alpha = 0.05$.

Discussion

Core Data: Correlation Analysis

Negative Pearson correlation coefficients for Cu, Zn, Ni, and P infer anthropogenic changes in Bluebonnet watershed have caused an increase of metals

with time. Anthropogenic activities increasing urbanization in the watershed include the development of roads, residences, and businesses. From 1941 to 2001, impervious surfaces increased from 0 to 28.5 hectares within Bluebonnet watershed, an increase of 7% (James Mitchell, personal communication).

Correlations between the analyte concentrations with depth were low. Calloway, et al., (1998) reported high Pearson correlation coefficients for six metals (Cd, Cr, Cu, Ni, Pb, and Zn) analyzed from marsh sediment. My results were similar to Calloway, et al., (1998) in that the lowest correlations occurred between Ni and P. Strong correlations between the metals are indicative of metals coming from the same source. The strongest correlation was between Cu and Cd concentrations. With urban development occurring within Bluebonnet Swamp watershed, it is unlikely that there was a constant source of metal input over time. In addition, the long, narrow shape of the swamp allows anthropogenic influences to occur on all sides; thereby, increasing the number of sources contributing to metal concentrations (Calloway, et al., 1998).

The changes in metal ($\mu\text{g/g}$)/%Al ratios with depth for Cores #1 and #2 infer changes in the watershed resulted in fluctuations of metal inputs. This is more apparent with Pb, as the additive was removed from automobile fuel in the mid 1970s. Increases in lead concentrations were more apparent after the peak Cs^{137} identifying 1963 (Figures 3.2 through 3.5). There is a significant increase in Zn concentrations within less than 12 cm from the soil surface indicating a significant increase of Zn pollution. Increases in Zn and Cu could be attributed to periodic

failures of a nearby sewage overflow valve, which is directed into the northeast corner of Bluebonnet Swamp. One such failure occurred during this study.

Pre-1963 metal ($\mu\text{g/g}$)/(%Al) ratios were calculated to estimate metal conditions prior to the majority of development within Bluebonnet Swamp watershed. When compared with post-1963 conditions, pre-1963 metal ratios were significantly lower for Cd inferring that changes in the watershed could be attributed to increasing urbanization. However, significant differences did not occur in pre- and post-1963 soil for Pb and Cr. Since Pb was not significantly correlated with depth and there was no significant difference in pre- versus post-1963 concentrations, the data might suggest there has been no substantial Pb increases in the watershed due to surrounding urbanization. However, the greater Pb ratio when compared with Pardue, et al. (1992) suggests that the material entering Bluebonnet Swamp might be enhanced anthropogenically due urbanizing developments within the watershed, but that the increases have been gradual over time.

Feldspar Marker Horizon Data

There were statistically significant differences in Pb, Cr, Ni, and Al concentrations for the transitional and interior landscape positions. Bulk density measurements, taken from core samples, revealed the interior landscape position (0.624 g/cm^3) had a greater organic content than the mineral soil within the transitional landscape (1.18 g/cm^3). The interior landscape position, with finer textured sediment greater in Al concentration and organic matter, is more conducive to absorption of metals. Stream flow from the various inflow points also contributed to the difference in metal concentrations between the landscape positions. Based on

visual observations, stream flow was less in the interior landscape portion of the swamp compared to the transitional areas. Hupp, et al. (1993) found that the analytes concentrated in areas where stream power was the lowest and where the quantity of fine-sized particles was the highest. Another explanation for greater metal concentrations in the interior landscape position could be attributed to a greater retention time of suspended sediments in overlying water.

Because trace and toxic metal concentrations can change with soil texture, Al normalized metal concentrations provide an effective tool to compare several soil types by eliminating the texture effect on concentration (Pardue, et al., 1992; Summers, et al., 1996; Tam and Yao, 1998). Once %Al normalized metal concentrations were not significantly different between the two landscape positions for Pb, Cr, and Ni. The statistical differences noted by the non-Al transformed data were caused by clay particle adsorption capacity and quantity, thereby masking the true concentration differences between sediment in the two landscape positions.

Sedimentation Disk Data

Analyte analysis of the sediment samples from the sedimentation disks for Pb, Cd, Cr, Cu, Zn, Ni, P, and Al revealed the lowest concentrations occurred within the channel landscape position and the greatest concentrations occurred within the interior landscape position. Once Al normalized, the analyte concentration ($\mu\text{g/g}/(\%\text{Al})$) ratios also revealed the greatest concentration occurred within the interior landscape. The interior landscape position contained greater Al concentrations and organic matter, which is more conducive to absorption of metals. Stream flow velocity was less in the interior landscape portion of the swamp (based

on visual observations) compared to the channel and transitional areas, which could have contributed to greater metal ($\mu\text{g/g}$)(%Al) ratios. (Hupp, et al., 1993).

Conclusions

There were significant differences between pre-and post-1963 concentrations for several metals. The increased metal influx into the swamp corresponded with a seven percent increase in impervious surfaces between 1963 and 2000. Background Pd and Cr metal ($\mu\text{g/g}$)(%Al) ratios for Bluebonnet Swamp were greater than ratios calculated by Pardue, et al. (1992) for coastal Louisiana sediment. Different accretion rates in the Pardue, et al. (1992) study could result in a “dilution” of metal concentrations if their study site was flooded more often than the study site of this paper.

This data provides a baseline level of analyte concentrations for an urban wetland environment in Baton Rouge, Louisiana and provides a means by which continued urbanization in the surrounding watershed can be compared.

CHAPTER 4: CONCLUSIONS

The sedimentation data retrieved from the Bluebonnet Swamp revealed statistically significant differences in current versus historic sedimentation rates. Current sedimentation rates are almost four times greater than historic rates. This increase could be attributed to increasing soil disturbances caused by road, residence, and business development within the surrounding watershed. Analysis of pre-1963 sediment from soil cores shows statistically that differences in metal concentrations exist between surface and sub-surface soils. Fluctuations in metal concentration profiles with depth indicate episodic increases over time. Soils within Bluebonnet Swamp; however, do have higher background concentrations for Pb, Cd, and Cr when compared to coastal Louisiana sediment which could suggest pollution from early 19th century activities or suggest differences in soil mineralogy. Little difference was concluded for sedimentation rates between the interior and transitional landscape; however, metal retention rates indicate the interior landscape is the primary sink for metals. It appears that the gradual change in land use within the Bluebonnet Swamp has lead to increases in metal concentrations and sedimentation rates over time.

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APPENDIX A: SEDIMENTATION DISK DATA

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
TR	2	43.35	38.12	366.88	4.22	83.98	23.51	28.25	2083.00	15371.61	0.39	0.22	0.04
TR	2	71.74	36.90	243.11	3.65	78.69	34.38	30.69	1709.25	13835.32	0.26	0.20	0.05
TR	2	53.00	39.21	361.33	4.63	89.68	23.00	28.98	2314.74	15200.52	0.35	0.28	0.05
CH	2	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	2	70.23	18.35	45.08	2.27	42.84	16.12	17.08	436.46	6910.04	0.26	0.10	0.03
TR	2	374.20	19.89	38.81	2.51	45.49	72.65	42.16	415.80	7284.18	0.14	0.06	0.04
TR	2	95.26	19.28	43.01	2.15	43.67	70.81	40.41	301.57	6710.30	0.18	0.07	0.02
CH	2	26.65	22.35	54.94	2.54	48.96	9.62	15.38	553.90	7257.62	0.29	0.11	0.03
TR	2	25.92	21.14	77.31	2.45	46.00	61.07	39.86	390.71	7637.06	0.03	0.12	0.03
TR	2	72.54	26.14	73.28	2.69	51.16	55.77	37.37	602.16	7650.98	0.18	0.11	0.04
TR	2	20.41	27.69	165.48	2.91	56.66	27.53	26.28	759.97	9960.74	0.16	0.12	0.04
CH	2	35.95	27.87	82.84	2.96	56.32	12.19	21.09	1150.91	9163.25	0.36	0.16	0.04
TR	2	30.54	26.67	71.83	2.82	54.83	21.56	22.99	557.82	8874.85	0.04	0.11	0.05
TR	2	23.46	25.50	71.03	2.87	55.36	17.75	20.87	555.95	9047.59	0.04	0.11	0.04
TR	2	48.59	31.58	83.87	3.10	64.05	53.09	44.48	774.39	11605.94	0.14	0.14	0.05
CH	2	25.56	44.63	131.23	3.61	57.15	10.79	19.27	1112.96	10331.58	0.27	0.15	0.06
IN	2	10.91	38.54	178.53	4.69	90.69	23.22	31.90	3760.04	17848.08	0.04	0.32	0.03
IN	2	23.33	38.42	176.95	4.78	94.78	29.74	34.01	2424.23	17039.68	0.03	0.30	0.03
IN	2	74.63	37.77	171.32	4.02	88.71	44.84	42.14	1871.90	17032.02	0.04	0.31	0.04
TR	2	67.95	31.20	84.26	3.67	74.04	30.40	31.34	967.54	12111.85	0.29	0.18	0.04
TR	2	59.05	28.90	89.32	3.29	66.66	22.72	29.37	841.08	12662.71	0.03	0.22	0.03
TR	2	50.54	27.94	82.58	3.28	61.60	23.62	25.95	841.74	11091.66	0.06	0.18	0.04
CH	2	2.39	29.66	85.32	3.34	63.62	11.68	19.47	899.90	12322.48	0.37	0.23	0.04

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
IN	2	3.67	39.41	1029.16	4.47	96.81	20.63	31.57	2366.35	20707.36	0.27	0.47	0.07
IN	2	3.61	37.88	674.03	4.62	99.55	17.34	30.25	2918.83	20883.88	0.15	0.47	0.05
IN	2	21.86	33.53	406.02	4.42	95.45	21.96	32.98	2259.62	22196.80	0.03	0.26	0.03
CH	2	227.95	14.53	45.65	2.10	38.51	8.45	13.35	370.52	5397.63	0.04	0.05	0.02
TR	2	30.34	23.64	76.75	3.50	64.01	12.55	18.33	676.47	8579.45	0.01	0.07	0.03
TR	2	16.54	21.90	82.44	2.98	63.07	13.33	17.89	856.17	9108.56	0.03	0.07	0.02
TR	2	101.70	24.07	75.73	2.86	67.04	11.71	18.59	660.77	9520.63	0.46	0.13	0.07
CH	2	127.64	27.26	57.30	2.39	45.50	6.19	11.81	475.50	4631.48	2.01	0.36	0.17
TR	3	0.94	72.52	287.46	<1.5	<2.6	24.02	15.69	1146.99	8840.05	5.98	1.14	0.50
TR	3	1.61	95.75	252.02	1.72	36.66	9.10	13.64	908.81	7634.32	6.37	1.11	0.47
TR	3	3.08	40.52	215.31	1.71	37.56	41.87	30.36	1329.06	9335.37	4.74	1.06	0.42
CH	3	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	3	37.44	8.23	31.42	1.06	15.15	3.44	8.02	286.42	4367.44	1.09	0.31	0.09
TR	3	146.49	10.47	29.22	0.80	14.43	3.20	6.91	344.93	4239.88	1.19	0.22	0.06
TR	3	30.03	7.12	30.60	0.72	12.85	3.96	6.71	214.17	4338.54	0.77	0.39	0.10
CH	3	2.44	6.83	45.45	0.75	55.30	4.86	7.71	351.43	4057.80	1.44	NA	NA
TR	3	3.17	10.09	52.44	0.82	10.58	4.41	8.99	393.66	5321.12	2.71	0.53	0.22
TR	3	3.02	12.60	51.59	0.72	9.71	4.58	8.32	409.60	4864.11	4.73	0.77	0.32
TR	3	4.21	12.19	58.20	0.78	13.48	5.81	10.20	589.25	6358.67	3.53	0.70	0.28
CH	3	0.36	34.91	102.71	0.19	7.88	9.76	12.24	489.07	5006.51	NA	NA	NA
TR	3	5.00	8.79	38.88	0.65	8.52	4.23	7.52	386.16	4877.54	1.27	0.36	0.13
TR	3	14.52	10.69	51.92	0.74	10.42	5.96	8.73	424.37	5293.15	2.16	0.42	0.19
TR	3	4.37	14.70	56.07	1.51	15.04	19.42	16.76	587.68	5640.29	2.75	0.59	0.31

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
CH	3	4.24	12.43	47.77	0.88	11.49	4.32	10.65	600.90	5046.90	2.39	0.53	0.25
IN	3	18.32	24.11	142.49	1.66	31.31	6.27	16.31	1358.97	9899.54	4.77	1.13	0.51
IN	3	18.31	27.53	156.01	1.86	30.94	5.72	16.10	1902.18	10592.09	5.00	1.23	0.52
IN	3	130.21	21.54	113.32	1.37	26.11	3.98	12.57	1960.82	8989.23	3.50	1.05	0.38
TR	3	2.54	23.04	73.98	1.13	17.41	6.37	12.88	636.76	7209.86	2.29	0.58	0.22
TR	3	3.34	41.43	81.48	1.16	17.90	4.89	11.91	651.12	6783.55	3.04	0.71	0.31
TR	3	0.73	120.53	217.47	0.91	15.38	5.58	11.78	639.24	6360.88	4.71	0.89	0.38
CH	3	1.11	49.78	125.97	0.65	12.18	5.13	9.40	412.70	5539.75	2.31	0.52	0.23
IN	3	0.45	62.85	288.30	1.98	37.60	7.64	18.45	1639.52	12718.85	8.95	1.72	0.83
IN	3	2.22	39.50	178.59	2.12	43.23	10.91	20.34	1568.52	13502.35	6.56	1.54	0.66
IN	3	4.14	42.30	180.84	1.86	32.58	8.47	17.36	1555.67	12099.27	8.32	1.72	0.79
CH	3	0.58	8.30	58.45	0.81	6.52	2.85	9.52	426.31	4380.31	2.13	0.64	0.21
TR	3	27.73	12.77	53.20	1.00	20.22	5.35	10.59	392.63	5038.57	2.28	0.48	0.26
TR	3	13.39	21.15	60.56	0.48	15.19	5.11	8.44	333.14	4503.92	2.11	0.45	0.26
TR	3	58.72	15.38	57.62	0.79	24.56	7.07	10.25	470.03	6554.88	3.86	0.74	0.39
CH	3	11.67	10.71	40.11	0.41	10.25	4.27	6.89	317.81	3861.15	1.83	0.36	0.20
TR	4	1.54	57.86	170.40	1.45	20.31	2.85	11.17	1018.62	9406.83	4.46	0.89	0.42
TR	4	1.61	62.69	131.18	0.80	11.87	4.20	8.54	596.18	8144.92	4.34	0.83	0.38
TR	4	5.09	40.75	144.25	1.14	16.67	3.60	10.79	928.75	9975.36	4.98	1.02	0.46
CH	4	3.55	12.16	33.89	0.28	<2.6	3.16	6.02	252.55	7133.86	NA	NA	NA
TR	4	57.13	25.42	126.58	0.17	<2.6	3.16	6.04	269.39	7055.26	1.48	0.32	0.15
TR	4	620.64	11.83	26.25	0.32	<2.6	1.90	4.62	305.18	5432.79	0.86	0.40	0.13
TR	4	60.08	15.63	27.60	<1.5	<2.6	2.23	4.18	182.95	5994.61	0.80	0.26	0.12

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
CH	4	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	4	39.17	34.70	35.25	<1.5	<2.6	2.06	3.72	233.78	4553.46	1.80	0.31	0.20
TR	4	32.02	16.15	92.84	0.87	10.18	3.36	6.63	251.69	4143.49	1.96	0.33	0.20
TR	4	22.10	13.63	34.66	0.64	10.19	3.52	6.45	254.63	4115.40	1.49	0.28	0.18
CH	4	8.13	18.59	46.68	0.84	13.33	4.06	9.59	358.98	6386.20	3.02	0.55	0.25
TR	4	16.62	21.67	54.24	0.98	13.98	7.09	10.67	363.38	8149.12	2.40	0.48	0.26
TR	4	15.94	20.80	57.37	0.96	11.79	6.88	10.25	389.74	9053.62	2.20	0.51	0.25
TR	4	12.82	32.07	61.96	1.19	14.12	6.61	10.82	401.11	8661.22	3.09	0.61	0.28
CH	4	4.15	31.38	62.41	1.09	14.50	6.37	10.50	575.34	7938.19	2.68	0.60	0.27
IN	4	96.00	28.71	134.41	1.83	31.75	7.83	17.48	1826.32	14592.71	3.58	0.90	0.43
IN	4	25.00	24.43	98.84	1.54	23.10	7.43	14.26	1100.92	11752.61	3.16	0.70	0.32
IN	4	24.99	28.57	123.08	1.67	26.83	7.57	16.18	1119.43	12667.35	3.86	0.95	0.46
TR	4	10.66	28.67	57.74	1.14	13.84	4.78	10.60	479.99	8252.96	1.70	0.48	0.21
TR	4	9.78	55.41	56.91	1.00	13.80	4.91	10.86	475.49	8096.94	1.56	0.45	0.21
TR	4	21.26	14.69	46.69	0.84	13.12	4.20	9.36	336.09	5650.85	1.78	0.39	0.21
CH	4	4.27	35.72	67.05	1.14	14.80	6.00	10.72	459.30	8866.29	1.96	0.53	0.23
IN	4	1.70	50.66	185.92	2.06	31.05	9.01	18.72	1235.72	15597.78	6.14	1.37	0.61
IN	4	3.59	33.44	156.61	1.99	29.39	10.56	18.50	1152.79	16266.81	5.28	1.34	0.57
IN	4	10.01	33.77	119.48	1.82	27.71	8.28	16.34	1260.99	14926.58	5.98	1.35	0.61
CH	4	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	4	34.02	12.60	43.91	0.53	10.80	4.14	6.09	231.31	4276.03	1.31	0.24	0.17
TR	4	32.66	12.95	33.68	0.93	11.68	3.84	6.19	212.18	4090.66	1.41	0.25	0.18
TR	4	58.47	14.98	50.62	0.93	22.36	6.48	9.78	360.41	7079.52	3.07	0.53	0.32

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
CH	4	5.86	14.83	38.55	0.68	10.26	3.49	6.06	249.52	4135.03	1.09	0.22	0.17
TR	5	2.67	68.63	195.89	2.42	37.11	6.13	14.80	1053.10	10649.35	5.06	1.00	0.39
TR	5	1.05	97.16	158.90	1.36	27.20	5.21	11.30	655.72	6716.96	5.92	0.94	0.40
TR	5	2.72	53.16	180.29	2.31	39.21	7.24	17.08	1046.92	11448.48	5.79	1.13	0.44
CH	5	11.09	24.86	132.74	1.62	29.03	5.36	11.59	962.33	8569.64	3.58	0.74	0.38
TR	5	1.21	14.55	54.29	1.58	37.80	11.36	15.70	390.53	9707.86	2.38	0.41	0.14
TR	5	81.13	24.84	115.22	1.60	92.99	8.80	11.93	328.46	6862.54	1.28	0.24	0.07
TR	5	30.91	19.20	82.39	1.61	59.51	7.08	10.53	260.40	5503.36	1.37	0.25	0.07
CH	5	27.97	18.90	45.44	1.20	36.31	4.04	14.09	233.26	4655.68	0.71	0.27	0.07
TR	5	7.05	20.97	65.00	1.35	19.93	32.73	31.17	493.79	6967.96	3.73	0.55	0.25
TR	5	6.82	19.93	64.86	1.12	19.37	42.91	30.67	453.55	5491.75	4.58	0.64	0.28
TR	5	12.59	17.96	63.20	1.45	22.18	7.69	13.25	595.72	7972.14	3.10	0.55	0.21
CH	5	1.58	32.73	56.16	1.56	32.57	4.85	12.27	517.38	4947.96	5.68	0.86	0.44
TR	5	39.55	16.90	54.18	1.25	21.37	16.70	20.40	442.07	7067.48	2.37	0.42	0.16
TR	5	26.94	17.28	59.03	1.28	20.01	29.99	33.64	483.57	8201.15	2.16	0.44	0.16
TR	5	11.63	28.16	63.96	1.49	21.01	7.46	13.43	660.65	8713.65	2.98	0.59	0.23
CH	5	8.57	22.90	62.46	1.38	21.84	33.49	21.52	502.49	6800.16	2.00	0.52	0.27
IN	5	128.49	26.69	137.28	2.20	37.85	6.55	18.01	2225.28	12381.69	3.92	0.85	0.36
IN	5	10.36	29.81	134.52	2.65	38.59	12.67	22.22	1773.21	11238.46	4.38	0.93	0.41
IN	5	10.00	32.00	136.23	2.31	36.62	41.01	26.52	1424.36	12283.87	4.30	0.93	0.40
TR	5	3.83	26.02	84.43	2.23	30.28	35.01	24.49	1023.90	10280.23	3.68	0.74	0.29
TR	5	2.55	38.72	75.75	2.01	27.67	13.03	16.99	833.04	8821.69	2.84	0.62	0.23
TR	5	4.71	21.98	86.61	1.98	25.98	7.48	19.60	1414.98	10475.56	4.09	0.70	0.30

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
CH	5	0.45	63.06	99.66	1.45	26.26	23.37	16.84	548.41	8371.29	3.98	0.79	0.43
IN	5	1.68	42.89	175.94	2.58	43.94	19.36	23.23	1235.36	14923.77	7.58	1.52	0.64
IN	5	2.66	34.11	137.99	2.34	44.59	11.93	21.55	1066.52	16069.62	5.79	1.35	0.53
IN	5	1.28	43.33	154.15	2.47	40.10	9.42	20.90	1492.77	14795.32	6.56	1.43	0.58
CH	5	1.13	33.02	84.45	1.27	17.86	6.98	10.94	447.25	7493.93	1.82	0.52	0.32
TR	5	8.62	21.14	64.90	1.75	29.45	29.01	18.35	539.62	6767.02	2.66	0.57	0.21
TR	5	4.87	20.21	56.67	1.27	23.86	6.60	10.70	489.19	5250.91	2.55	0.46	0.19
TR	5	15.77	22.34	62.27	1.28	29.37	7.97	12.08	449.30	8085.34	3.50	0.61	0.27
CH	5	14.38	14.96	42.24	0.91	20.17	4.25	7.75	329.35	3899.34	1.90	0.30	0.28
IN	5	2.13	37.89	88.40	1.68	31.24	7.73	14.51	1004.76	9366.14	5.09	0.91	0.44
IN	5	2.18	43.46	112.62	1.84	35.65	9.31	16.81	1115.20	12192.29	5.66	1.07	0.49
IN	5	2.30	37.43	114.21	1.55	32.97	11.09	16.39	843.68	12036.90	5.03	1.01	0.46
TR	6	1.21	45.86	182.01	2.35	43.98	8.11	15.83	1057.66	11883.69	5.38	0.98	0.48
TR	6	0.79	53.95	126.16	2.01	35.35	5.87	12.05	1114.95	8464.06	6.59	1.07	0.53
TR	6	0.93	47.16	165.60	2.42	41.00	5.88	15.81	1143.14	10261.46	7.31	1.27	0.58
CH	6	5.12	22.52	213.49	1.60	27.88	5.66	10.74	708.06	6875.87	5.02	0.83	0.35
TR	6	1.05	22.68	80.09	1.36	61.71	6.00	9.13	288.50	4896.10	1.90	0.41	0.12
TR	6	17.98	19.90	52.46	1.07	33.03	4.19	7.80	289.56	3914.26	1.39	0.21	0.10
TR	6	13.76	18.58	88.11	1.15	56.69	6.36	9.56	244.37	5075.16	1.17	0.22	0.09
CH	6	5.69	13.98	30.92	0.90	23.83	5.73	5.80	172.25	2951.30	1.00	0.16	0.05
TR	6	1.45	26.88	56.63	1.44	21.89	10.11	14.25	534.81	5766.94	4.05	0.66	0.30
TR	6	1.36	28.19	65.90	1.33	21.80	6.66	12.15	564.14	5492.30	6.26	0.92	0.42
TR	6	2.76	22.11	120.45	1.57	25.12	7.36	13.13	568.00	7391.41	4.17	0.75	0.31

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
CH	6	0.36	79.23	80.91	1.69	29.44	6.85	12.69	658.10	4950.49	7.94	1.15	0.57
TR	6	4.79	23.21	56.19	1.40	23.44	7.35	11.67	439.68	6493.96	2.52	0.54	0.23
TR	6	8.88	24.21	58.30	1.34	23.15	6.97	12.11	425.59	7121.28	2.59	0.49	0.23
TR	6	4.47	27.89	61.76	1.51	25.44	6.97	12.97	532.19	7224.45	3.51	0.64	0.30
CH	6	12.86	31.47	54.83	1.40	22.28	17.38	17.81	472.34	6262.80	2.67	0.51	0.23
IN	6	177.89	35.45	150.20	2.68	44.39	6.21	18.75	2282.34	11763.51	4.14	0.93	0.42
IN	6	10.93	29.62	131.25	2.20	34.30	6.61	17.39	1463.25	11382.20	5.68	1.18	0.54
IN	6	9.83	33.13	144.84	1.97	34.05	7.73	18.02	1532.26	12597.30	5.60	1.19	0.55
TR	6	3.25	14.58	60.39	1.35	23.98	6.92	13.96	587.29	8897.15	2.50	0.56	0.23
TR	6	0.91	15.15	67.54	1.51	26.72	8.09	15.88	657.02	8930.18	2.70	0.64	0.27
TR	6	2.37	14.91	65.69	1.48	24.70	6.01	14.89	622.91	9378.02	2.78	0.62	0.25
CH	6	7.20	13.73	51.60	1.18	19.05	7.04	13.24	527.04	7603.67	3.44	0.57	0.26
IN	6	2.15	37.37	125.12	1.78	34.69	10.48	19.20	1044.26	13851.53	9.35	1.61	0.78
IN	6	3.29	29.18	117.26	1.70	38.41	13.63	21.52	806.10	15189.88	5.67	1.25	0.57
IN	6	4.46	30.02	135.73	2.02	38.74	10.12	20.07	1147.51	14028.69	8.33	1.57	0.74
CH	6	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	6	28.98	14.47	58.36	1.31	29.03	6.33	11.99	454.23	6820.93	3.38	0.63	0.32
TR	6	8.60	16.96	56.01	0.86	21.83	8.01	11.00	483.16	5451.90	4.21	0.66	0.37
TR	6	27.00	20.14	55.55	1.12	30.31	6.77	11.81	506.23	7314.64	3.59	0.58	0.34
CH	6	2.22	21.45	48.75	0.69	19.69	4.76	8.15	366.80	4657.41	2.29	0.35	0.20
IN	6	9.89	22.59	97.41	1.53	32.00	11.06	17.55	790.35	10885.78	4.70	0.88	0.48
IN	6	13.20	24.86	124.16	1.79	37.57	11.76	19.52	900.04	12491.86	5.58	1.11	0.55
IN	6	9.70	26.88	124.49	1.40	30.16	13.78	19.31	827.18	12046.28	6.10	1.14	0.60

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
TR	7	5.91	33.71	177.16	1.57	34.16	10.93	16.04	1013.13	9427.72	3.69	0.78	0.31
TR	7	5.17	21.57	158.68	1.59	32.64	9.92	14.54	1164.05	8848.01	5.28	0.97	0.41
TR	7	3.98	34.51	201.99	2.38	39.06	12.95	19.01	1369.80	10588.28	7.55	1.36	0.56
CH	7	24.56	18.12	114.81	1.36	24.25	8.95	12.88	808.11	7198.59	3.15	0.59	0.30
TR	7	5.37	22.48	94.57	1.24	72.71	6.37	10.81	337.05	5727.04	1.53	0.42	0.12
TR	7	124.64	19.67	94.62	1.09	83.63	7.49	9.56	282.45	4499.55	1.33	0.34	0.11
TR	7	142.98	28.39	138.75	1.30	114.78	8.49	11.64	313.45	6149.12	1.75	0.39	0.12
CH	7	18.68	11.98	50.48	0.92	44.67	4.12	8.33	263.58	4320.02	0.62	0.12	0.08
TR	7	8.65	16.53	56.31	7.30	24.32	22.02	15.03	471.28	6318.19	2.61	0.55	0.22
TR	7	6.37	15.60	46.25	1.11	24.39	10.11	10.88	451.50	5018.32	3.90	0.72	0.32
TR	7	14.17	16.11	59.55	1.52	29.66	8.11	13.36	600.75	6693.31	3.04	0.62	0.25
CH	7	0.91	28.69	56.03	1.54	34.81	44.02	17.61	616.70	5652.64	5.64	0.84	0.45
TR	7	26.50	16.65	49.73	1.35	31.21	8.61	11.89	408.82	5817.77	2.38	0.50	0.20
TR	7	19.87	17.52	58.68	1.53	33.22	43.52	18.68	476.63	6855.21	2.46	0.53	0.21
TR	7	14.84	19.37	62.39	1.42	29.07	8.74	13.59	551.42	8225.50	3.88	0.70	0.31
CH	7	58.42	17.17	52.60	1.20	24.38	7.30	11.27	423.95	6375.52	2.50	0.46	0.22
IN	7	4.75	24.48	139.49	2.23	40.86	5.28	17.38	2288.59	11952.36	4.48	0.98	0.46
IN	7	2.15	32.65	132.10	1.97	39.26	6.28	16.44	1519.44	9862.22	5.22	1.09	0.61
IN	7	0.91	41.34	167.63	3.12	37.96	1.27	15.55	2715.29	9965.26	5.46	1.16	0.62
TR	7	14.78	19.44	64.69	1.55	28.38	6.92	14.48	615.97	7597.40	2.03	0.51	0.20
TR	7	8.15	20.76	64.54	1.64	30.58	6.18	13.72	631.61	7214.41	2.27	0.54	0.23
TR	7	3.24	24.74	69.22	1.47	28.99	6.37	13.91	603.97	7244.37	2.45	0.52	0.21
CH	7	4.14	24.27	60.76	1.29	24.08	6.47	12.60	629.74	6970.60	4.20	0.64	0.32

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
IN	7	4.49	35.07	158.24	2.18	48.63	16.09	20.39	918.91	14536.81	8.51	1.58	0.72
IN	7	6.64	28.27	131.77	2.23	54.52	15.23	22.38	1051.22	16139.97	5.71	1.31	0.56
IN	7	18.73	31.04	136.44	2.12	54.56	15.14	21.91	944.30	14654.10	7.00	1.49	0.60
CH	7	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	7	73.33	19.83	67.42	1.52	42.23	7.83	13.79	549.91	6980.52	3.13	0.61	0.26
TR	7	48.85	18.36	65.09	1.50	40.04	8.06	13.49	543.32	7057.85	3.41	0.63	0.28
TR	7	21.10	22.15	66.18	1.41	35.19	9.42	13.71	513.09	7945.04	3.50	0.64	0.30
CH	7	6.54	14.44	43.67	0.60	19.43	4.22	7.16	425.83	3860.92	2.33	0.34	0.21
IN	7	3.34	26.68	104.43	1.45	38.51	8.69	16.47	1110.01	11025.33	4.69	0.96	0.46
IN	7	3.30	27.07	119.06	1.59	43.90	10.43	17.94	1025.20	12540.25	5.42	1.14	0.52
IN	7	2.66	32.46	113.55	1.39	37.02	10.62	16.38	848.32	12279.37	5.79	1.13	0.54
TR	8	7.51	30.56	192.42	1.77	41.00	6.02	13.49	1721.61	9591.78	5.10	0.92	0.48
TR	8	5.56	24.40	168.56	1.66	36.06	5.02	11.58	1861.17	8902.09	5.51	1.03	0.52
TR	8	4.15	30.77	197.54	2.03	42.33	4.65	13.85	2027.84	9729.48	6.45	1.22	0.55
CH	8	25.37	21.40	118.36	1.19	29.06	6.42	11.43	1157.19	7607.94	3.41	0.66	0.33
TR	8	66.91	22.69	75.45	1.52	55.87	6.54	11.61	439.37	5755.61	1.58	0.33	0.13
TR	8	31.69	23.36	105.09	1.00	79.61	7.02	9.75	357.28	5032.17	1.58	0.27	0.14
TR	8	47.31	19.47	93.12	0.98	76.78	5.39	8.76	296.86	3740.77	1.48	0.21	0.06
CH	8	13.54	18.58	47.77	1.16	27.29	6.01	9.89	396.18	6163.17	0.83	0.30	0.09
TR	8	13.50	17.11	69.29	1.10	23.15	6.05	11.59	667.93	6857.43	2.97	0.63	0.30
TR	8	4.60	20.09	60.18	1.13	20.09	7.21	11.90	476.68	5603.89	2.97	0.49	0.24
TR	8	15.24	17.16	63.19	1.22	22.69	5.81	13.36	1021.59	7001.07	3.41	0.71	0.33
CH	8	1.18	31.33	63.54	0.91	22.12	5.78	11.27	805.88	5776.85	8.74	1.41	0.70

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
TR	8	64.89	18.33	56.53	0.92	21.88	7.53	11.44	509.96	6685.76	2.76	0.51	0.23
TR	8	82.49	17.28	54.61	0.87	22.47	8.63	11.62	482.67	6440.67	2.86	0.52	0.25
TR	8	22.68	22.35	68.46	1.13	25.33	9.17	12.94	629.39	8545.54	3.86	0.75	0.36
CH	8	83.87	20.94	60.21	0.97	23.44	7.49	11.29	540.01	6734.86	2.69	0.57	0.25
IN	8	14.75	32.49	151.86	1.86	43.48	7.25	17.76	2178.91	12004.69	4.29	1.06	0.47
IN	8	5.97	30.00	142.75	1.76	41.78	6.73	16.24	1870.14	10742.57	8.96	1.95	0.81
IN	8	9.41	30.39	153.30	1.97	42.18	7.13	17.13	1803.48	11236.41	5.59	1.29	0.55
TR	8	38.10	21.73	68.06	1.64	32.67	5.93	14.56	650.80	8348.52	2.67	0.75	0.28
TR	8	13.51	18.67	59.74	1.31	28.76	7.93	13.87	542.36	6731.58	2.15	0.63	0.25
TR	8	10.50	21.14	66.46	1.26	27.15	12.23	16.43	593.61	7705.12	2.81	0.72	0.28
CH	8	1.61	22.55	55.14	1.05	25.73	8.37	12.98	442.98	6776.20	1.54	0.49	0.20
IN	8	7.24	29.87	140.99	1.79	50.43	42.47	31.49	934.24	15179.79	7.21	1.54	0.71
IN	8	25.33	24.61	112.50	1.65	46.18	18.19	22.21	817.02	14895.01	4.73	1.38	0.51
IN	8	15.06	31.58	141.05	2.05	52.11	34.91	25.59	1120.04	16405.45	6.33	1.53	0.65
CH	8	23.71	11.14	43.87	1.25	23.49	3.70	9.89	403.99	4410.70	0.65	0.30	0.10
TR	8	44.25	19.43	66.54	0.96	38.14	8.80	13.41	684.74	7867.54	3.40	0.73	0.34
TR	8	34.66	18.96	68.64	1.07	33.10	7.28	12.02	660.53	7187.13	3.16	0.71	0.34
TR	8	44.25	24.43	69.54	1.02	36.06	8.60	12.89	560.01	7680.82	3.17	0.69	0.36
CH	8	7.31	16.02	49.33	0.85	24.03	4.63	8.84	655.56	4336.46	2.24	0.41	0.22
IN	8	13.43	25.38	111.79	1.58	45.05	10.82	17.26	889.75	11340.86	4.37	1.04	0.48
IN	8	9.29	29.72	127.32	1.81	44.76	9.76	18.38	1229.07	12283.53	5.28	1.25	0.57
IN	8	2.80	32.55	136.41	1.75	43.25	10.96	17.80	1237.67	12547.22	5.96	1.32	0.62
TR	9	6.14	43.49	108.87	3.81	105.66	8.68	15.45	672.16	5633.35	2.69	0.57	0.26

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
TR	9	7.39	34.20	92.34	2.85	89.96	9.73	13.35	450.30	4061.62	2.19	0.40	0.21
TR	9	4.72	34.28	92.73	2.27	86.29	10.43	13.01	353.28	3932.80	1.54	0.31	0.16
CH	9	7.69	31.78	54.61	2.86	53.53	8.43	13.60	508.77	5390.24	1.54	0.40	0.15
TR	9	18.71	54.76	184.09	5.42	93.86	7.11	20.38	1902.63	6933.96	4.83	1.00	0.51
TR	9	10.69	24.99	172.28	1.54	35.06	5.19	11.45	1486.39	8130.52	6.10	1.17	0.58
TR	9	12.33	23.93	192.85	1.44	35.66	4.13	13.09	1872.89	9933.52	6.16	1.29	0.62
CH	9	17.77	16.46	104.54	0.25	10.91	2.22	6.84	1461.31	6118.98	3.47	0.76	0.38
TR	9	24.52	1.90	70.77	<1.5	<2.6	5.79	7.55	576.66	7592.95	3.13	0.71	0.33
TR	9	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	9	19.04	<1.5	71.67	<1.5	<2.6	6.10	7.72	1051.56	7824.76	3.44	0.77	0.35
CH	9	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	9	61.90	<1.5	59.13	<1.5	<2.6	3.45	4.89	560.48	6468.74	2.88	0.64	0.30
TR	9	68.34	<1.5	61.89	<1.5	<2.6	4.33	5.25	620.95	7193.57	2.43	0.57	0.28
TR	9	20.34	36.16	84.04	<1.5	<2.6	4.19	6.35	809.11	8812.88	3.85	0.82	0.38
CH	9	122.65	27.61	66.44	0.90	18.87	7.10	10.08	596.84	7754.63	2.69	0.66	0.28
IN	9	40.34	30.84	150.90	1.50	34.73	5.14	14.59	2382.29	12791.83	4.51	1.12	0.52
IN	9	41.75	33.30	146.08	0.70	21.85	6.09	13.06	1633.97	12402.95	4.88	1.26	0.52
IN	9	31.17	23.74	144.14	0.43	15.56	6.40	13.06	1408.15	13090.06	4.97	1.20	0.55
TR	9	90.62	9.56	70.27	<1.5	<2.6	3.45	9.88	610.23	9381.54	2.14	0.68	0.25
TR	9	31.59	15.94	64.58	1.32	22.33	4.65	13.01	581.69	8194.43	2.41	0.63	0.28
TR	9	5.57	21.78	71.99	1.13	23.09	10.60	13.58	592.39	8406.00	2.42	0.64	0.27
CH	9	6.27	18.48	61.77	1.15	26.07	16.28	15.12	489.06	8302.23	2.20	0.56	0.26
IN	9	18.39	32.07	135.59	1.82	82.76	31.32	24.82	1245.16	18231.73	6.81	1.48	0.69

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
IN	9	51.66	28.56	119.11	1.77	80.46	45.35	25.90	1070.49	18062.86	5.56	1.39	0.61
IN	9	20.30	28.70	134.62	2.05	83.96	70.89	30.35	1382.77	18458.20	6.78	1.51	0.70
CH	9	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	9	46.46	18.26	66.49	0.90	30.09	7.40	12.84	765.33	8788.90	3.68	0.80	0.37
TR	9	45.38	20.14	75.96	1.07	30.93	68.71	21.63	776.65	8706.45	3.62	0.74	0.39
TR	9	54.98	17.43	66.50	1.23	34.50	15.16	14.27	1116.82	9346.01	3.26	0.75	0.38
CH	9	60.92	13.01	56.17	0.86	25.26	5.13	9.69	716.39	5462.34	2.59	0.47	0.27
IN	9	40.33	22.70	147.57	1.70	58.42	11.65	17.37	940.82	12790.80	4.24	1.01	0.47
IN	9	24.18	31.55	123.12	1.52	58.73	10.14	17.84	1112.70	12446.51	5.47	1.24	0.57
IN	9	17.33	27.46	119.77	1.55	64.51	13.64	18.81	1105.53	14722.30	5.23	1.23	0.57
TR	10	18.02	22.32	142.53	1.63	60.37	9.02	15.19	1213.33	10696.38	3.18	0.79	0.35
TR	10	28.88	23.70	166.74	1.84	37.15	7.14	13.61	1172.58	9403.62	5.12	1.07	0.50
TR	10	10.36	28.35	174.99	1.86	67.99	22.11	17.90	2240.55	11847.83	4.75	1.16	0.49
CH	10	58.81	20.09	116.54	0.97	20.30	4.99	10.49	1367.75	8304.89	3.31	0.76	0.37
TR	10	316.72	12.72	46.72	0.68	22.78	3.77	8.08	411.78	5746.70	0.97	0.36	0.13
TR	10	42.80	13.70	74.71	0.43	39.09	6.97	7.94	327.70	5352.39	1.76	0.36	0.18
TR	10	43.84	16.37	81.44	0.51	44.99	6.40	8.37	316.14	5751.95	1.69	0.32	0.15
CH	10	49.03	9.49	32.00	0.45	9.67	3.37	6.86	318.24	5221.31	0.48	0.25	0.10
TR	10	33.39	13.54	63.87	0.48	7.42	5.96	9.69	565.95	8517.49	2.57	0.58	0.30
TR	10	9.92	10.86	54.74	0.14	<2.6	4.69	6.65	465.72	6426.33	3.10	0.62	0.30
TR	10	22.47	13.95	61.30	0.34	3.76	4.71	9.30	773.19	8407.92	3.83	0.80	0.37
CH	10	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	10	85.66	19.17	59.60	0.34	6.02	6.09	8.89	507.05	8110.14	3.28	0.72	0.32

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
TR	10	44.77	19.83	59.75	0.22	4.07	5.77	8.57	551.49	7349.23	2.90	0.63	0.31
TR	10	40.78	20.61	68.78	1.30	23.67	8.26	13.96	613.24	9259.54	3.46	0.75	0.35
CH	10	17.08	19.41	60.90	0.83	21.95	7.12	11.13	514.58	7493.04	3.06	0.64	0.31
IN	10	92.91	33.32	147.55	1.56	73.24	24.81	21.04	2236.97	13045.69	4.66	1.10	0.50
IN	10	66.54	30.34	148.85	1.67	68.87	23.78	19.98	1970.82	12198.57	5.28	1.19	0.58
IN	10	55.07	29.69	176.56	1.67	70.56	23.76	20.09	1698.82	12578.03	5.00	1.18	0.55
TR	10	108.84	14.31	56.03	0.82	20.47	4.66	11.54	549.96	7755.37	1.91	0.56	0.24
TR	10	89.31	15.40	55.72	0.75	22.28	4.66	10.76	514.46	7050.17	1.88	0.51	0.24
TR	10	25.20	11.49	48.95	0.54	16.65	4.04	9.73	464.48	6562.34	1.66	0.43	0.22
CH	10	5.26	16.57	59.98	0.85	23.81	14.65	16.27	523.95	8401.14	1.95	0.52	0.24
IN	10	16.32	26.95	137.84	1.51	68.46	16.09	20.72	1199.04	16934.40	7.46	1.48	0.77
IN	10	17.69	34.90	129.38	1.53	75.38	29.43	23.33	1392.54	17226.48	6.55	1.47	0.72
IN	10	36.81	33.91	144.27	1.58	77.46	31.00	23.52	1224.29	17287.45	7.24	1.55	0.73
CH	10	3.51	11.33	55.22	0.53	12.83	3.82	8.91	341.96	5471.47	0.98	0.38	0.15
TR	10	123.64	18.02	67.34	1.05	33.58	7.44	13.52	669.30	9256.46	3.59	0.80	0.37
TR	10	114.29	18.72	71.57	0.92	29.61	7.22	12.11	583.62	8726.47	3.58	0.78	0.39
TR	10	72.55	19.68	77.01	0.89	28.50	7.05	13.48	933.24	9703.79	4.03	0.86	0.46
CH	10	6.81	14.05	56.33	0.57	17.05	3.02	8.29	848.09	4964.20	2.36	0.50	0.25
IN	10	43.97	21.73	120.07	1.13	59.00	13.18	17.47	832.68	14243.58	4.44	1.06	0.50
IN	10	34.06	26.44	147.30	1.30	63.37	13.90	19.28	871.43	14691.13	5.31	1.27	0.55
IN	10	32.46	26.03	124.83	1.28	57.92	14.24	18.41	786.79	14883.03	5.63	1.34	0.58
TR	11	21.65	24.26	170.59	1.32	55.57	7.85	<2.6	1499.79	10104.11	4.11	0.97	0.42
TR	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
TR	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CH	11	122.64	22.42	114.95	1.02	28.34	5.39	11.24	1490.43	8834.96	2.80	0.72	0.31
TR	11	155.44	21.54	61.94	1.26	41.13	3.88	11.68	590.48	7605.50	1.81	0.59	0.18
TR	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CH	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CH	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CH	11	9.71	34.33	64.09	0.67	18.21	7.25	10.89	450.27	7919.30	3.16	0.67	0.30
IN	11	243.90	28.81	141.69	1.30	62.42	23.12	19.98	2338.28	11396.68	4.31	1.03	0.48
IN	11	80.41	32.76	144.65	1.59	70.09	28.10	22.37	2257.93	11966.13	5.37	1.19	0.56
IN	11	50.63	31.44	144.36	1.56	69.41	37.57	30.11	1625.38	13344.44	5.48	1.26	0.61
TR	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CH	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
IN	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
IN	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Position	Collection	Dry wt. (g)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)	%C	%N	%H
IN	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CH	11	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TR	11	17.04	19.56	64.97	0.71	31.47	13.31	17.82	555.93	8750.19	3.01	0.71	0.33
TR	11	23.55	15.57	65.77	0.60	25.08	10.56	13.99	527.50	8071.72	3.31	0.70	0.36
TR	11	21.04	17.77	66.43	0.95	31.42	9.01	15.69	938.72	9210.77	3.94	0.82	0.41
CH	11	4.70	21.27	179.91	0.36	14.66	10.43	13.75	556.58	4906.32	2.39	0.49	0.26
IN	11	15.76	22.20	117.64	1.31	56.01	13.50	19.18	916.26	12740.63	4.73	1.09	0.53
IN	11	51.54	28.00	117.84	1.12	60.08	14.33	18.52	705.64	14209.64	5.98	1.36	0.57
IN	11	29.84	31.68	123.46	1.31	59.96	15.39	19.98	939.58	14474.22	5.21	1.26	0.55

* Not Analyzed

APPENDIX B: SOIL CORE DATA

Depth (cm)	Core #	Position	Dry wt. (g)	Cesium (pCi/g soil)	Bulk Density (g/cm ³)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)
0-2	1	IN	62.2	0.447	0.4341	19.888	130.16	0.731	22.203	5.68	14.84	981.37	10406.68
2-4	1	IN	60.3	0.194	0.4209	23.220	125.87	0.490	22.251	6.93	15.10	1008.62	11066.22
4-6	1	IN	98.7	0.207	0.6889	17.890	107.16	0.483	13.462	4.54	13.99	1124.11	12348.10
6-8	1	IN	89.3	0.257	0.6233	16.238	154.19	0.559	24.355	8.52	15.58	676.39	13020.35
8-10	1	IN	89.1	0.558	0.6219	16.610	187.30	0.421	42.049	7.50	16.22	656.53	12334.84
10-12	1	IN	90.0	0.915	0.6282	18.054	169.83	0.409	39.764	9.64	15.89	555.46	12035.85
12-14	1	IN	69.1	0.720	0.4823	20.070	134.83	0.338	26.002	9.47	16.60	539.36	13646.70
14-16	1	IN	128.5	1.142	0.8969	14.104	97.14	0.039	17.926	9.67	14.79	646.36	16146.75
16-18	1	IN	95.0	0.616	0.6631	13.055	80.82	0.236	19.117	6.85	14.07	1031.03	14148.49
18-20	1	IN	113.0	0.155	0.7887	20.010	91.41	2.198	43.769	14.37	21.53	625.65	15564.46
20-22	1	IN	112.0	0.252	0.7817	21.568	80.51	1.605	278.23	14.14	20.38	686.31	14775.57
22-24	1	IN	65.2	0.307	0.4551	21.719	81.13	1.680	104.53	11.89	20.38	732.11	14930.25
0-2	2	TR	136.5	0.054	0.9525	29.082	69.20	2.754	53.290	11.42	16.56	530.46	8821.65
2-4	2	TR	84.9	0.109	0.5924	27.515	65.59	2.830	56.480	12.83	18.20	536.34	9335.49
4-6	2	TR	170.9	0.191	1.1926	31.462	65.56	3.034	59.511	13.24	18.92	486.28	10040.77
6-8	2	TR	172.6	0.184	1.2047	26.786	59.80	2.894	56.717	13.65	19.67	435.95	10021.97
8-10	2	TR	206.3	0.106	1.4398	23.577	88.58	3.356	51.275	8.03	17.06	368.42	7671.39
10-12	2	TR	192.0	0.058	1.3401	23.958	52.81	3.092	55.478	9.24	18.63	428.93	9415.31
12-14	2	TR	192.5	0.175	1.3436	25.055	145.71	2.896	58.962	22.16	23.38	457.09	9166.63
14-16	2	TR	173.8	0.250	1.2132	26.522	62.23	2.984	64.088	12.99	19.71	437.45	11089.83
16-18	2	TR	201.8	0.370	1.4083	24.224	63.46	2.799	63.229	13.05	18.38	432.73	10152.76

Depth (cm)	Core #	Position	Dry wt. (g)	Cesium (pCi/g soil)	Bulk Density (g/cm ³)	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)
18-20	2	TR	146.0	0.404	1.0191	24.895	71.42	3.059	65.306	17.26	20.55	435.72	10536.46
20-22	2	TR	150.8	0.449	1.0525	28.897	70.61	3.591	79.513	18.04	22.97	472.00	11327.89
22-24	2	TR	199.0	0.167	1.3893	14.431	73.68	1.351	56.971	15.79	17.64	474.00	13616.82
24-26	2	TR	193.8	0.113	1.3529	10.648	88.62	0.334	43.938	14.20	14.99	451.71	12573.97
26-28	2	TR	165.1	0.145	1.1521	6.577	75.11	0.000	37.615	12.66	13.84	449.08	12428.31
28-30	2	TR	188.8	0.132	1.3176	6.923	74.92	0.000	44.455	15.64	15.17	451.23	13917.56
30-32	2	TR	183.4	0.072	1.2801	4.955	75.41	0.000	37.285	14.03	15.21	394.02	13441.75
32-34	2	TR	236.7	0.049	1.6519	0.961	65.44	0.000	22.406	12.69	13.18	385.83	12067.67
34-36	2	TR	227.1	0.026	1.5849	0.000	54.75	0.000	14.392	15.71	11.56	391.83	10993.29
36-38	2	TR	187.8	0.013	1.3110	0.000	51.51	0.000	6.211	13.62	10.05	427.01	10093.81
38-40	2	TR	196.0	NA*	NA	0.000	56.22	0.000	13.530	12.72	9.47	443.87	11842.69
40-42	2	TR	187.3	NA	NA	0.000	56.88	0.000	4.327	10.57	8.59	417.24	11531.91
42-44	2	TR	216.2	NA	NA	0.000	87.80	0.000	0.000	10.35	8.34	379.20	11571.84
44-46	2	TR	183.6	NA	NA	0.000	66.38	0.000	0.000	28.83	16.97	372.13	12743.51

*Not Analyzed

APPENDIX C: FELDSPAR MARKER HORIZON DATA

Position	Dry wt (g)	Accum. Rate (cm/yr)	Bulk Density (g/cm ³)	%Mineral Matter	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)
TR	48.72	2.673	0.303	92.75	19.08	152.31	0.971	27.18	5.85	12.86	861.35	9419.9
TR	95.36	4.276	0.370	91.69	22.59	170.85	1.614	35.44	6.30	15.09	1083.78	8802.9
TR	60.22	1.711	0.585	91.34	19.21	147.03	2.134	33.18	10.43	17.32	1020.97	8529.7
TR	23.24	1.069	0.361	92.25	21.00	155.15	1.998	33.05	8.00	18.93	1379.70	8386.8
TR	36.31	2.138	0.282	87.56	23.26	261.39	1.825	48.48	6.94	15.72	1203.12	10869.3
TR	47.60	0.214	3.693	97.79	14.18	68.96	1.045	49.52	7.97	11.77	316.71	5297.1
TR	77.13	1.497	0.856	97.96	15.78	69.67	1.120	51.77	8.27	12.10	324.52	5480.0
TR	141.25	3.207	0.732	98.07	14.00	55.85	0.881	38.31	5.62	8.46	307.94	5263.7
TR	162.65	2.566	1.053	97.89	19.29	92.88	1.371	70.99	10.55	13.96	332.46	5966.7
TR	137.89	4.919	0.466	96.95	19.27	97.26	1.366	74.03	8.58	12.93	324.95	5652.7
TR	62.55	2.244	0.463	95.60	16.92	61.34	1.240	37.64	9.21	13.71	597.46	10009.6
TR	80.01	2.672	0.497	96.17	14.12	55.25	1.333	21.80	7.95	15.20	448.90	9202.9
TR	38.61	2.621	0.245	95.25	16.48	72.71	1.089	17.35	6.64	10.79	581.47	7813.8
TR	37.22	1.711	0.361	93.44	16.88	63.82	1.221	20.16	8.74	15.30	581.99	9031.3
TR	35.36	2.138	0.275	93.41	15.90	72.40	1.287	21.44	6.31	14.13	572.88	8531.6
TR	34.23	2.993	0.190	90.81	18.05	157.06	1.203	20.57	6.37	12.77	566.15	8210.7
TR	95.21	6.202	0.255	92.17	20.42	71.45	1.274	23.45	7.67	13.35	523.47	8638.8
TR	51.32	0.855	0.997	95.62	19.62	66.56	1.271	24.96	9.74	14.42	513.13	9574.3
TR	61.52	2.138	0.478	93.17	18.43	64.31	1.079	18.99	7.76	12.41	483.18	8582.1
TR	45.28	0.428	1.756	97.00	14.95	51.40	1.176	20.94	10.16	15.63	397.33	7844.2
TR	59.17	1.283	0.766	96.51	16.80	63.43	1.210	41.86	21.49	22.81	516.25	10532.7

Position	Dry wt (g)	Accum. Rate (cm/yr)	Bulk Density (g/cm ³)	%Mineral Matter	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)
IN	91.38	2.138	0.710	97.68	14.33	58.03	1.419	25.09	12.11	19.39	492.25	8630.0
IN	33.02	2.032	0.270	96.53	12.00	47.54	0.930	17.13	4.78	10.35	469.26	7105.6
IN	168.39	3.209	0.872	98.06	13.53	49.32	1.135	23.34	6.47	13.32	423.76	7325.0
IN	50.00	3.421	0.243	95.09	13.66	54.02	1.235	22.51	6.71	13.75	488.75	7993.2
IN	93.90	3.421	0.456	96.49	16.54	68.90	1.312	26.11	4.42	12.88	543.36	8033.8
IN	65.64	3.421	0.319	96.15	15.22	62.76	1.373	22.89	5.36	13.18	469.22	8834.8
TR	27.00	1.711	0.262	92.01	22.99	109.99	1.538	28.28	3.87	15.07	838.51	9566.8
TR	32.12	3.421	0.186	95.00	23.81	107.05	1.414	24.71	4.41	13.59	817.41	8396.2
TR	54.07	1.926	0.156	91.65	26.98	138.79	1.615	52.04	7.96	16.06	839.47	11037.7
TR	50.47	3.743	0.224	89.35	27.08	269.82	1.793	59.47	20.03	18.74	1181.54	11266.5
TR	47.78	1.924	0.412	91.83	24.41	123.43	1.723	51.39	7.14	15.98	1142.15	11379.8
IN	20.87	1.711	0.203	86.26	22.67	149.30	1.650	58.53	11.83	18.09	808.67	13339.6
IN	33.52	2.993	0.186	86.19	17.99	88.01	1.421	49.85	10.06	14.60	648.25	10601.2
IN	84.34	3.209	0.437	93.90	22.56	94.12	1.743	68.80	14.86	19.66	727.47	15468.3
IN	57.26	2.887	0.329	91.68	22.22	185.45	1.491	58.12	12.26	18.47	687.05	14206.1
IN	77.27	3.421	0.375	92.37	25.02	104.94	1.612	64.93	15.95	19.93	791.12	16081.3
IN	58.32	2.566	0.378	91.30	27.27	100.19	2.056	60.35	14.04	18.64	814.65	13725.7
TR	92.96	2.993	0.516	94.75	16.05	89.74	1.165	37.83	9.23	14.32	559.89	9987.8
TR	55.39	2.138	0.430	95.43	15.17	69.45	1.265	28.42	6.11	12.49	649.32	7882.4
TR	31.40	2.354	0.222	93.91	18.73	98.05	1.207	30.26	5.97	11.84	632.98	7529.1
TR	34.53	1.283	0.447	92.42	21.48	106.42	1.538	56.23	10.59	16.41	876.10	11301.0
TR	52.08	2.566	0.337	94.62	20.14	77.87	1.285	36.20	8.75	14.04	645.98	9563.8

Position	Dry wt (g)	Accum. Rate (cm/yr)	Bulk Density (g/cm ³)	%Mineral Matter	Cu (ug/g)	Zn (ug/g)	Cd (ug/g)	Pb (ug/g)	Cr (ug/g)	Ni (ug/g)	P (ug/g)	Al (ug/g)
TR	41.85	2.138	0.325	94.76	18.69	68.55	1.174	30.16	5.19	12.08	709.25	7210.2
IN	81.17	4.276	0.315	92.44	26.35	138.71	1.708	58.26	11.65	17.72	777.68	12575.6
IN	40.52	2.138	0.315	92.51	25.74	147.73	1.610	58.24	11.56	18.45	853.17	13065.2
IN	54.79	4.276	0.213	90.13	27.10	147.72	1.477	58.56	11.65	17.37	737.29	12321.3
IN	58.10	3.315	0.291	87.26	35.42	250.80	1.845	65.79	28.05	23.93	814.29	12931.8
IN	54.40	3.421	0.264	90.85	23.42	110.50	1.512	55.06	12.21	17.63	728.84	12852.8
IN	47.88	3.421	0.232	89.87	25.96	353.78	1.764	44.21	9.03	16.48	693.37	10727.1

VITA

Renee Lynn Sanders was born in New Orleans, Louisiana, on December 27, 1976, to Linda Lehmann Sanders. Upon graduation in 1994 from Central High School in Harrison, TN, she attended The University of Tennessee at Knoxville. After a six-month internship at Walt Disney World during 1997, she graduated magna cum laude in December 1998. She has attended Louisiana State University since January 1999.

Ms. Sanders is currently a candidate for the degree of Master of Science in Oceanography and Coastal Sciences. After graduation she plans to continue working as a wetland consultant at an environmental consulting firm in Baton Rouge, Louisiana.